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XIX. *The Analysis of Bubbles in Glass.* *By the* Research Staff *of the General Electric Co., Ltd., London.* (*Work conducted by* J. W. Ryde *and* R. Huddart.)

Received March 17, 1923.
(Communicated by C. C. Paterson, O.B.E., M.I.E.E.)

ABSTRACT.

In order to distinguish bubbles generated by chemical action in glass from those introduced by mechanical processes spectroscopic tests are made for the presence of nitrogen. In order to liberate the gas from the bubbles a specimen of the glass is placed in one limb of a quartz U-tube and mercury in the other, and the glass is heated and then disintegrated by sudden cooling, the tube being plunged into cold water at the same time that the mercury is thrown on to the glass.

The presence of bubbles is one of the most serious defects of glass. It has long been recognised that bubbles might arise in two ways, first by the generation of gas in the glass itself, second by the introduction of air or furnace gases during ladling, pouring or stirring. Bubbles due to these two causes could be distinguished easily if the nature of the gas contained in them could be determined, for bubbles

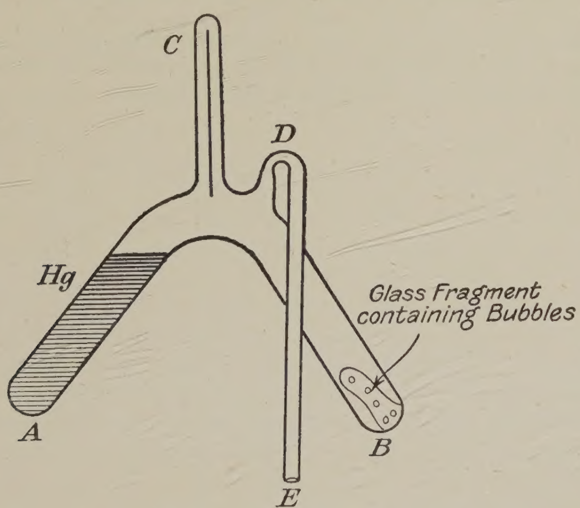


Fig. 1.

due to the second cause should contain nitrogen, while in general those due to the first should not.

The problem of determining the nature of the gas in a bubble may not appear at first sight easy to solve. We have found that it is an extremely simple matter. A piece of the glass containing bubbles is placed in one limb of a small quartz U-tube (Fig. 1); the other is three-quarters filled with mercury. The U-tube is evacuated with all the usual precautions against the presence of gas absorbed on the walls and sealed-off from the pump. The limb containing the glass is then heated till the glass is just soft; it is then plunged into water, the cold mercury from the other limb being thrown on the hot glass at the same time. This process

is repeated several times, if necessary. By this process the glass is broken into small fragments and the gas contained in the bubbles liberated. A discharge is then excited in the capillary tube *C* by a Tesla apparatus and the spectrum examined for nitrogen. It has been found possible to distinguish quite definitely between bubbles which contain nitrogen and those which do not.

DISCUSSION.

Mr. J. GUILD expressed surprise that the spectrum of nitrogen should be distinguishable in the presence of mercury vapour, which might be expected to carry most of the discharge and to mask the effect of the nitrogen.

Dr. E. A. OWEN inquired what precautions were taken to prevent atmospheric gases from entering the tube along with the mercury.

Dr. R. T. BEATTY suggested that if the method could be made quantitative it might be used to find out what becomes of the gas which disappears from the interior of a discharge tube during the life of the latter.

Mr. J. W. RYDE, in reply to the discussion, said that the nitrogen spectrum would be completely masked by that of mercury if the tube were warm, and would be only just distinguishable at ordinary temperatures. In practice, therefore, one limb of the tube is immersed in liquid air whereby satisfactory results can be obtained. In filling the tube with mercury every precaution is taken, by drying and boiling the mercury and so on, to prevent the admission of gaseous impurities. Greater difficulty is experienced, however in getting rid of the gases adsorbed on the silica walls of the tube, which have to be heated repeatedly with a blow-pipe. The method does not readily lend itself to quantitative applications, as the line intensities are much affected by the fact that the discharge takes place in a mixture of gases.

XX. *A Simple Regenerative Vacuum Device and Some of its Applications.* By

H. P. Waran, *M.A., Ph.D. (Cantab.), F.Inst.P.*

Received March 24, 1923.

ABSTRACT.

The Paper deals with the difficulties arising from residual traces of air fouling the vacuum above the mercury column in syphon gauges and other devices. A remedy is suggested in the form of a small attachment taking the shape of bent capillary tubing ending in a bulb. This enables the air to be repeatedly pushed into the vacuum of this bulb, the mercury at the bottom of the capillary preventing the subsequent return of the air. With such an arrangement fitted to the top of a syphon gauge the height of the column of mercury becomes a true measure of the gas pressure, subject only to the definite correction for the vapour pressure of mercury and temperature. The device is regenerative in the sense that, irrespective of any progressive fouling of the vacuum, a fresh air-free vacuum is automatically created by it every time it is brought into action. As typical examples of the wide field of utility of the device its application to mercury barometers and mercury vapour lamps is also briefly discussed.

One of the devices finding constant use in vacuum work is the simple syphon gauge illustrated in Fig. 1 (*a*). The readings of such a gauge are made on the assumption that the space above the mercury in the closed limb is a perfect torricellian vacuum containing nothing but a trace of mercury vapour which, at the average temperature of about 20°C. has a negligible vapour pressure of about 0·001 mm. of mercury. For convenience in measuring the difference of mercury level in the two limbs of the gauge, it is customary to have them side by side. This arrangement introduces difficulties in the way of filling the gauge with mercury without locking any small bubbles of air in the closed limb. In practice even with the best of care small bubbles of air do get locked in the closed limb of the gauge, especially when a vacuum process of filling the gauge with boiling mercury is not adopted. At the first opportunity when the gauge comes under operation these bubbles expand into the torricellian vacuum above the mercury in the closed limb. Considering that the volume available for expansion is generally very small, and that the bubbles to start with are very nearly at atmospheric pressure, it is easy to see that quite small bubbles are enough to cause an error in reading of about 1 mm. When the actual pressure in the system is only a millimetre or two, this is a serious error of about 50 per cent.

Further, the extent of the error due to this is uncertain, and it can be determined only by comparison with another standard connected to the system or by measuring the gas pressure accurately by some other means. Apart from this uncertainty, the error is also variable with the pressure, since the volume of the vacuous space above the mercury varies with the pressure. In addition to these troubles, if the gauge comes into operation frequently and is to be used for a long time connected to an apparatus, there is a progressive deterioration of the vacuum in the closed limb. This is due to the film of air carried along the walls by the mercury flowing in and out of the closed limb periodically. For such gauges it is useful to fit a simple air-trap, as shown in Fig. 1 (*c*), and this would arrest the forward progress of the air film to a great extent.

Because of such inherent defects the syphon gauge has always remained a rough indicator for low pressures, and its readings have never been relied upon to

an accuracy greater than a few tenths of a millimetre of mercury. If means can be devised to deal successfully with such accumulations of air fouling the vacuum and ensure the vacuum above the mercury being practically perfect, there is no reason why it could not be used to measure the pressures directly with an accuracy of about 0·001 mm. Its directness and simplicity are greatly in its favour and the limit is set only by the accuracy of the kathetometer used to measure the difference in level.

The simplest way of dealing with such residual gases seems to be that of pushing them out into a subsidiary chamber and preventing their return back into the system. In a syphon gauge this can easily be achieved by attaching the small regenerative extension R, as indicated in Fig. 1(b). This device consists of a small length of capillary tubing T, bent to the shape shown and ending in the auxiliary bulb B.

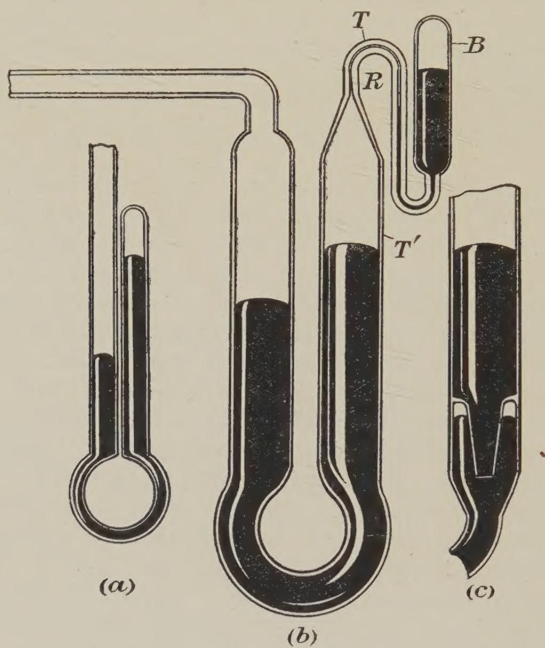


FIG. 1.

To start with, the gauge, including the regenerative attachment, is completely filled with mercury as usual. When it is connected to a low-pressure system mercury level goes down in B and T', forming torricellian vacua in the two chambers. The little mercury that remains in the lower portion of B serves to cut off communication between B and T'. Into this vacuum the residual bubbles of gas locked in the tubes during the filling operations can rise. Now, if the open limb is opened to the atmosphere, the mercury rises up in T' and passes into B, forcing the residual gases above it into B. As the pressure goes down again the mercury level goes down in T', sucking a fresh air-free torricellian vacuum above it. Thus the vacuum above the mercury is practically perfect, and the difference in heights of the mercury in the two limbs is an exact measure of the gas pressure within an accuracy of about 0·001

mm. mercury. The arrangement described is regenerative in the sense that this action is repeated automatically every time the gauge comes into action.

Such a regenerative device is applicable to many laboratory devices in one form or other.

One such principal field of application is supplied by the mercury barometers which, in essentials, are elaborated syphon gauges. As prominently pointed out in the Meteorological Office observers' handbook,* the chief defect of mercury barometers is their gradually increasing error, due to the progressive accumulation of air in the space above the mercury. Considering that a barometer to be of any use for meteorological purposes must be capable of maintaining an accuracy greater than 0·01 mm. for periods reckoned in years, it is easy to see how small and slow a

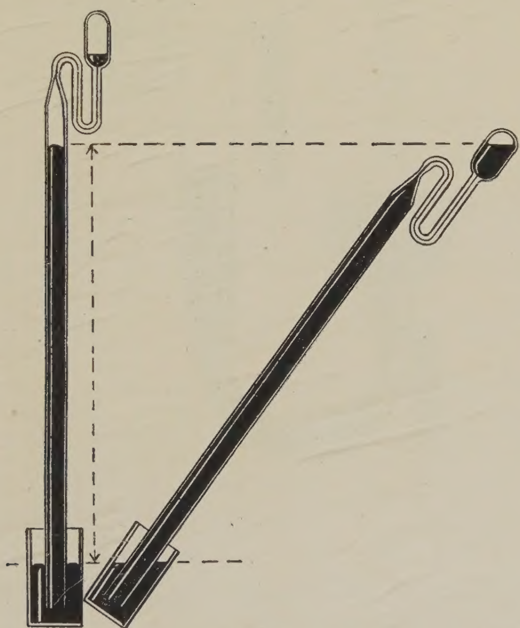


FIG. 2.

leakage is sufficient to make the instrument of no use. A small regenerative attachment of the type described is easily fitted on to a barometer of any pattern, and then it can deal with such accumulations of air quite easily. All that one has to do is to periodically tilt the barometer a little, as shown in Fig. 2, in the case of portable instruments of the Kew pattern, or screw up the base screw in the case of the Fortin type of standard barometers. Especially is this device of value for standard barometers. The device has the great advantage that it is of small dimensions, and can readily be fitted to existing types of barometers without necessitating any serious structural alterations.

Another instance of its application is in the case of a simple type of mercury vapour lamp. In a lamp of the design shown in Fig. 3 the vacuum in the arc space

* 1919 Edition, p. 22.

is automatically renewed every time a little air is let in, and sucked back by a filter pump, or the lamp may be tilted suitably. In fact, the lamp exhausts itself to start with, without the aid of any high vacuum pump. As such it ought to be very useful in many laboratories where the requisite facilities for the production of high vacunm do not exist.

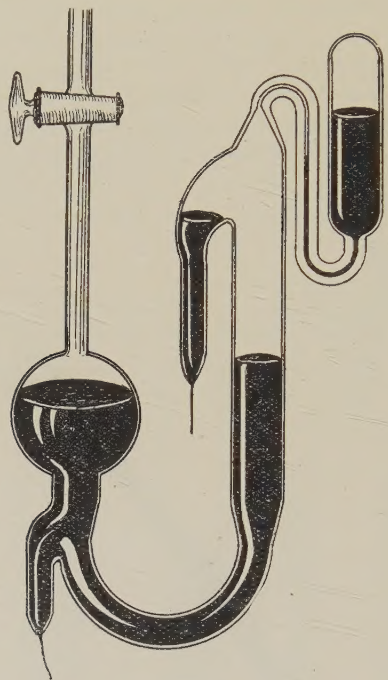


FIG. 3.

Doubtless there are many other similar instances where the principle of the device could be used in one form or other.

In conclusion, I must thank Prof. A. W. Porter, D.Sc., F.R.S., for his sympathetic interest in this device.

DISCUSSION.

Dr. R. T. BEATTY said that the device is a remarkably simple and effective one. If it could be put on the market in combination with an oil trap and a drying tube it would fill a long-felt want.

Dr. G. B. BRYAN said that if the capillary tube were too small there might be difficulty in getting the mercury to move air bubbles along it, as there is a tendency for the mercury to slip past a bubble. He inquired as to the kind of glass employed.

Dr. E. A. OWEN mentioned a somewhat similar device which has been in use for some time at the National Physical Laboratory.

Mr. F. A. GOULD (communicated): The author has drawn attention to a device which has been known for many years to users of precision barometers.

In the "Travaux et Memoires du Bureau International," Tome II (published in 1883), there is a description of a barometer in which practically the same device is used. It is recorded there that the object of the device was not entirely fulfilled to the satisfaction of the Bureau

International, as it was found that " the complete expulsion of the air from the vacuum-space of the barometer required the passage of a considerable quantity of mercury upwards through the instrument, a procedure which probably introduced fresh small bubbles of air from the lower end of the barometer."

The device for renovating the vacuum has also been used in this country. A reference standard mercury barometer incorporating this design was constructed by Dr. Aston, formerly of the Royal Aircraft Factory, Farnborough, during the war, and is still in use at Kidbrooke, while a similar principle was adopted in an experimental standard barometer which, though designed at the National Physical Laboratory in 1913, was not filled until 1922. The efficiency of the device has not yet been tested at the N.P.L.

The reference made by the author to the possibility of securing an accuracy of 0·001 mm. of mercury in the use of a syphon gauge requires some qualification. It is well known that the capillary action of mercury is not negligible, even in tubes of comparatively large diameter, e.g., 1 in. Exact equality in the amount of the capillary depression in each limb of the gauge cannot be relied upon, and it would be necessary to select a syphon tube of internal diameter at least 1·3 in. in order that the differential capillary error should not exceed 0·001 mm. Other causes would render this degree of accuracy difficult to secure.

The reference to the meteorological barometer is misleading, and an estimate of 0·1 mm. would be far nearer the truth than 0·01 mm. for all ordinary purposes. It is usual to insert an air trap in the tubes of all Kew-pattern barometers (i.e., those barometers with uniform, contracted scales and no fiducial point), but it is doubtful whether it would be practicable to fit the " vacuum-renewal " device to the ordinary portable types of mercury barometers.

Mr. J. Guild said that he was particularly interested in the application to mercury lamps and would like to know more of the author's experiences in this connection. The models shown were on a small scale and suitable for low voltages, but where a bright discharge is exacted the vapour pressure of the mercury becomes considerable and it might be expected that in these circumstances the mercury seal would cease to be effective.

Dr. D. Owen asked if the author could furnish some experimental results. Had he, for instance, data of inter-comparison of two syphon barometers constructed as described and subjected to the same conditions ?

The Author, in reply to the discussion, said that the device could very readily be combined with an oil trap and drying tube. Various difficulties have to be overcome in practice, but there is none in getting the mercury to move the bubbles provided a capillary tube of 0·5 mm. diameter be used. It was not surprising that the idea should have occurred to others, but he was not previously aware of the fact and had thought that other workers might find the device useful. He had not had an opportunity to obtain experimental data, but he hardly thought a syphon barometer would be capable of a total accuracy of 1 μ. That figure represented the maximum error due to imperfection of the vacuum. The device would not be effective for an indefinite period, but might increase the life of a barometer by some years. The mercury lamps of which he had had experience were some taking 2 amp. at 110 volts which he had made for laboratory use. In such lamps when hot the mercury rises about 1 cm. The construction of the apparatus is such that there is no tendency for the rise in vapour pressure to break the mercury seal.

In regard to the previous work on the subject in France, he concluded from his own inquiries that this had produced but little impression here, and he trusted his Paper would serve to advance the matter.

XXI. *Application of the Eötvös Torsion Balance to the Investigation of Local Gravitational Fields.* *By* Capt. H. SHAW, *M.Sc., F.Inst.P., and* E. LANCASTER-JONES, *B.A.* (*Cantab.*).

RECEIVED FEBRUARY 24, 1923.

ABSTRACT.

In a Paper read before this Society on February 9, the Eötvös Torsion Balance was described in detail, and the theory of its operation considered, the preparation of suitable torsion wires was mentioned, but no practical tests with the instrument were discussed.

In view of the sensitivity of the balance, which, as previously stated, measures derivatives of gravity of the order of 10^{-9} C.G.S. units, it was anticipated that a gravitational survey of the laboratory would disclose the varying effects of the neighbouring masses of the walls, pillars, &c. The balance was therefore set up at different stations in the laboratory, and the derivatives at each station measured. The measurements at several stations were checked by repetition, and the results compared with the theoretical values.

The mutual consistency of the results obtained at each station, and their general agreement with the calculated effects exceeded expectations, as the local gravitational field varied so rapidly that the theoretical assumption of a uniformly varying field in the neighbourhood of a station was obviously vitiated.

I.

THE experiments were conducted in a basement room of the new Science Museum building, South Kensington, which was the only room available for the purpose. The temperature variation from day to day, which is an important factor, never exceeded about 2°, except in the change over from winter to summer conditions in the heating arrangements of the laboratory. In order to avoid disturbances due to radiation, the laboratory was kept in total darkness, except when an observation was being made, the radiation from the electric light and the presence of the observer, for about 30 seconds, being insufficient to disturb the reading in that period.

This basement room, measuring 7·3 metres by 6·6 metres (*see* Figs. 1 and 2), was adjacent to a solid bank of earth, while on the remaining sides it was bounded by a 9 in. brick wall, connecting massive columns of re-inforced concrete, which, considerably affect the local gravitational conditions.

Other considerations also rendered the room to some extent unsuited to our purpose, it being situated in the basement of a massive building which was constantly undergoing important structural alterations, while in addition objects

of considerable weight were frequently being moved to and from adjacent rooms.

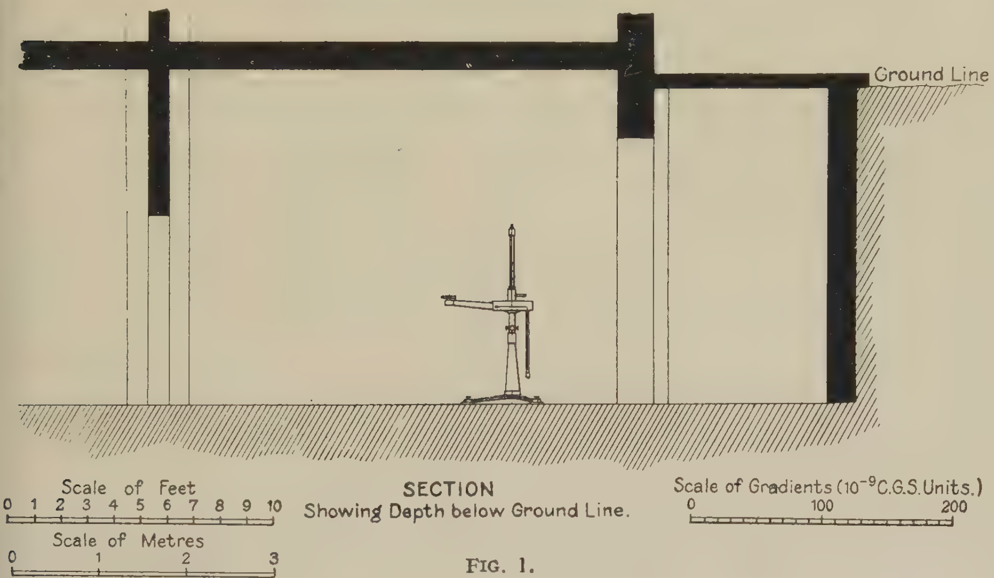


FIG. 1.

II.

From a consideration of the theory of the instrument in the Paper referred to above, we obtained the fo mula

$$n_a - n = A \sin 2a + B \cos 2a + C \sin a + D \cos a \quad \ldots\ldots\ldots \quad (1)$$

where

$$\left(\frac{\partial^2 U}{\partial y^2} - \frac{\partial^2 U}{\partial x^2}\right) = \frac{A\tau}{D'K}$$

$$\frac{\partial^2 U}{\partial x \partial y} = \frac{B\tau}{2D'K}$$

$$\frac{\partial^2 U}{\partial x \partial z} = -\frac{C\tau}{2D'mhl}$$

$$\frac{\partial^2 U}{\partial y \partial z} = \frac{D\tau}{2D'mhl}$$

$\frac{\tau}{D'K}$ and $\frac{\tau}{2D'mhl}$ being instrumental constants.

In his investigations Eötvös made observations at intervals of 72° requiring

only five readings to complete a set, but by increasing the number of observations, and taking the readings at each 60°, we are able to simplify the calculations.

The six equations resulting from putting $a=0°$, 60°, 120°, 180°, 240°, 300° in equation (1) give us

$$A=\frac{1}{\sqrt{3}}\left(n_{60}-n_{120}-\frac{n_0-n_{180}}{2}\right)$$

$$B=\frac{n_0+n_{180}}{2}-n$$

$$C=\frac{1}{\sqrt{3}}\left(n_{60}-n_{240}-\frac{n_0-n_{180}}{2}\right)$$

$$D=\frac{n_0-n_{180}}{2}$$

while in addition we find that

$$n_0+n_{120}+n_{240}=n_{60}+n_{180}+n_{300} \quad \ldots \ldots \quad (2)$$

Equation (2) thus provides us with a simple and convenient check on the observations, and any error of sensible magnitude can be detected immediately, and the observations repeated before the instrument is moved.

During this investigation the values of the instrumental constants $\frac{\tau}{D'K}$ and $\frac{\tau}{2D'mhl}$ were $134{\cdot}48\times10^{-9}$ and $44{\cdot}17\times10^{-9}$ respectively, so that we get

$$\left.\begin{aligned}
\left(\frac{\partial^2U}{\partial y^2}-\frac{\partial^2U}{\partial x^2}\right)&=77{\cdot}64\left(n_{60}-n_{120}-\frac{n_0-n_{180}}{2}\right)\times10^{-9}\\
\frac{\partial^2U}{\partial x\partial y}&=67{\cdot}24\left(\frac{n_0+n_{180}}{2}-n\right)\times10^{-9}\\
\frac{\partial^2U}{\partial x\partial z}&=25{\cdot}50\left(n_{240}-n_{60}+\frac{n_0-n_{180}}{2}\right)\times10^{-9}\\
\frac{\partial^2U}{\partial y\partial z}&=44{\cdot}17\left(\frac{n_0-n_{180}}{2}\right)\times10^{-9}
\end{aligned}\right\} \quad \ldots \ldots \quad (3)$$

III. Verification of Results.

(*a*) As the local gravitational field varied rapidly, it appeared desirable to check the results at a few stations by repeating observations with new initial azimuths and subsequent azimuths at intervals of 60°. The results of such a repetition at one station Y with initial azimuths 0°, 10°, 20° . . . . 50° are given in Table I., and the

derivatives calculated for each set and reduced to common axes in and perpendicular to the magnetic meridian.

TABLE I.

Initial azimuth	$\left(\frac{\partial^2 U}{\partial y^2} - \frac{\partial^2 U}{\partial x^2}\right)$	$\frac{\partial^2 U}{\partial x \partial y}$	$\frac{\partial^2 U}{\partial x \partial z}$	$\frac{\partial^2 U}{\partial y \partial z}$	$\sqrt{\left(\frac{\partial^2 U}{\partial x \partial z}\right)^2 + \left(\frac{\partial^2 U}{\partial y \partial z}\right)^2}$	Gradient Direction, from initial azimuth.	Gradient direction (magnetic)
	10^{-9}	10^{-9}	10^{-9}	10^{-9}	10^{-9}		
0°	−308·4	− 34·96	−123·5	− 53·0	134·35	23°·10′	23°·10′
10°	−253·0	− 82·40	−133·1	− 24·6	136·35	12°·30′	22°·30′
20°	−278·8	−131·0	−137·0	− 7·12	137·2	3°·00′	23°·00′
30°	− 73·48	−147·6	−136·4	+ 15·36	137·3	− 6°·30′	23°·30′
40°	+ 33·76	−151·6	−132·6	+ 33·96	138·2	−16°·20′	23°·40′
50°	+133·1	−141·5	−122·0	+ 60·3	136·1	−26°·20′	23°·40′
Means	...	...	...	...	136·6	...	23°·15′
Max. error	...	...	...	...	2·2	...	0°·45′

REMARKS.—The maximum error of 1·6 per cent. is smaller than was anticipated in view of the non-uniformity of the local field.

(*b*) An additional check is provided by repeating the observations at one station with constant initial and subsequent azimuths, *e.g.*, results for station Z are shown below for a series of readings which were repeated daily for a week.

TABLE II.

Day.	Azimuth.						$\frac{\partial^2 U}{\partial x \partial z}$	$\frac{\partial^2 U}{\partial y \partial z}$	$\sqrt{\left(\frac{\partial^2 U}{\partial x \partial z}\right)^2 + \left(\frac{\partial^2 U}{\partial y \partial z}\right)^2}$	Gradient Direction Magnetic.
	50°	110°	170°	230°	290°	350°				
Mon.	16·93	18·73	19·01	16·49	17·04	17·75	−37·49	9·71	38·74	215°·30′
Tues.	16·92	18·73	19·00	16·50	17·04	17·77	−37·74	9·28	38·86	216°·10′
Wed.	16·93	18·72	19·01	16·49	17·05	17·75	−36·98	9·71	38·23	215°·20′
Thurs.	16·92	18·73	19·00	16·48	17·03	17·75	−37·74	9·71	38·78	215°·30′
Friday	16·92	18·72	19·00	16·48	17·04	17·75	−37·23	9·71	38·48	215°·20′
Sat.	16·90	18·71	19·00	16·47	17·01	17·73	−37·87	9·50	39·03	215°·55′

(*c*) In order to compare the results obtained at one station after an interval of three months, observations were taken at Station Z in November, 1922, and again in February, 1923. During the interval between these observations the balance had been set up at several stations and transported to the Imperial College of Science for demonstration before this Society, whilst the lower suspension wire had been removed on a few occasions.

TABLE III.—*Observed Results.*

Date	Initial Azimuth.	$\left(\frac{\partial^2 U}{\partial y^2} - \frac{\partial^2 U}{\partial x^2}\right)$	$\frac{\partial^2 U}{\partial x \partial y}$	$\frac{\partial^2 U}{\partial x \partial z}$	$\frac{\partial^2 U}{\partial y \partial z}$	$\sqrt{\left(\frac{\partial^2 U}{\partial x \partial z}\right)^2 + \left(\frac{\partial^2 U}{\partial y \partial z}\right)^2}$	Direction of Maximum Gradient Magnetic.
		10^{-9}	10^{-9}	10^{-9}	10^{-9}	10^{-9}	
14/11/22	0°	−120·7	29·5	−31·62	−21·20	38·07	213°·50′
10/2/23	0°	−119·5	28·24	−31·625	−21·42	38·18	214°·30′

IV. Comparison of Results at Different Stations.

Table IV. gives the values of the four derivatives at all the stations in the laboratory at which observations were made, and illustrates the rapidity with which these derivatives vary, especially in the neighbourhood of the attracting masses. In Fig. 2 the stations are plotted and the resultant horizontal gradients represented in magnitude and direction by arrows. The gradient is the resultant of $\frac{\partial^2 U}{\partial x \partial z}=\frac{\partial g}{\partial x}$ and $\frac{\partial^2 U}{\partial y \partial z}=\frac{\partial g}{\partial y}$, and therefore indicates the direction in which gravity varies most rapidly, and the amount of variation per centimetre in that direction. If the attraction g at any point (say Z) is known by pendulum methods, the attraction at any other point (say Y) can be calculated by integrating the resultant gradient along any line joining Z and Y.

Table IV.

Station.	$\left(\frac{\partial^2 U}{\partial y^2}-\frac{\partial^2 U}{\partial x^2}\right)$	$\frac{\partial^2 U}{\partial x \partial y}$	$\frac{\partial^2 U}{\partial x \partial z}$	$\frac{\partial^2 U}{\partial y \partial z}$	$\sqrt{\left(\frac{\partial^2 U}{\partial x \partial z}\right)^2+\left(\frac{\partial^2 U}{\partial y \partial z}\right)^2}$	Maximum Gradient Direction Magnetic.
	10^{-9}	10^{-9}	10^{-9}	10^{-9}	10^{-9}	
A ...	...	...	33·82	− 37·77	50·70	19°·50′
B ...	...	...	− 25·25	− 26·95	36·93	22°·50′
C ...	...	...	+ 30·62	− 2·65	30·74	155°·3′
D ...	...	...	+ 3·1	− 19·43	19·63	79°·10′
E ...	−177·15	+ 30·93	− 62·75	− 17·67	65·19	196°
F ...	−180·33	34·29	− 55·00	− 33·57	64·44	221°·20′
G ...	− 61·56	16·47	13·88	− 14·35	19·94	313°· 0′
H ...	− 61·96	− 2·69	32·25	− 15·57	36·21	334°·15′
J ...	− 94·53	6·72	− 15·25	0·88	15·30	176°·20′
K ...	−111·22	16·81	− 10·75	− 11·48	15·72	226°·55′
L ...	− 66·33	203·72	14·50	3·97	15·04	15°·20′
M ...	− 50·44	11·43	15·88	− 0·66	15·89	357°·35′
N ...	− 62·36	15·46	3·125	1·99	3·706	32°·30′
O ...	− 85·00	13·45	− 2·00	− 8·39	8·627	256°·10′
P ...	− 89·35	20·51	2·125	− 15·68	15·82	277°·50′
Q ...	− 90·16	28·24	2·375	− 22·30	22·43	276°·50′
R ...	− 90·55	31·61	6·00	− 39·31	39·77	278°·50′
S ...	−107·64	10·42	+ 36·59	− 21·42	42·40	329°·40′
T ...	−106·84	56·84	− 32·26	− 43·06	53·80	223°· 0′
U ...	− 32·18	16·81	26·52	− 9·28	28·09	19°·20′
V ...	−135·04	8·07	− 31·1	2·67	31·22	184°·50′
W ...	−319·36	91·48	128·52	12·02	129·1	185°·20′
X ...	−388·20	61·2	126	30·25	129·80	193°·40′
Y ...	−308·40	− 34·96	123·5	53·0	134·35	203°·10′
Z ...	−119·5	28·24	− 31·62	− 21·42	38·18	214°·10′
W_1 ...	...	...	+102·25	−170·9	199·2	187°·50′
Y_1 ...	...	...	+125·50	−148·8	194·6	194°·10′
T_1 ...	...	...	− 15·9	− 66·05	68·0	237°·30′

The curves in Fig. 2 denote the lines of equal resultant gradient, and are numbered to correspond with the magnitude of the gradient, whilst their direction is always normal to the curve.

The arrows and curves show very markedly the gravitational attraction of the neighbouring masses. Although it was impossible to set up the balance very near the walls and pillars, their effects can clearly be traced, particularly that of the north wall (which is a solid bank of earth extending several metres beyond the laboratory on each side). The line of stations R Q P O N shows where the gradient of the attraction of this wall is counterbalanced by that of the opposite walls and

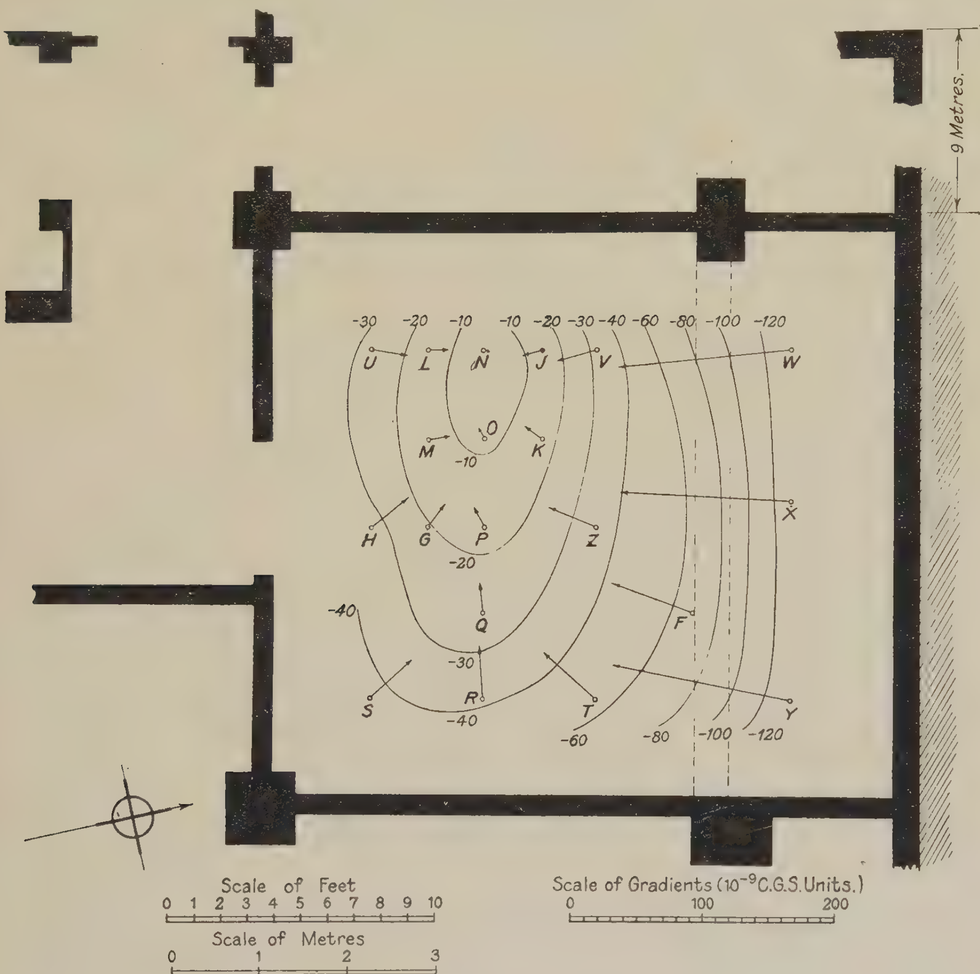


FIG. 2.

pillars. Near the point N the gradient vanishes completely and the gravitational attraction is a maximum.

The point of maximum gravity, near N, is more on the west side of the room than would be expected from the approximate symmetry of the laboratory. This appears to be due to masses not represented in the figure, the laboratory being nearly in the north-west corner of the basement of the building.

V. Comparison of Observed Results with Theoretical Values.

Owing to the large number of disturbing masses in the neighbourhood of the laboratory, and the impossibility of calculating the effect of each, only a rough comparison of the observed results with the theoretical effects was possible. It is, however, fairly easy to demonstrate that the observed magnitudes are of the same order and act in the same direction as the gradients due to the more important local masses. The gravity potential at the origin due to a mass, m grams, at the point (a, b, c) is

$$U_0 = \frac{mG}{r}$$

where $r^2 = a^2+b^2+c^2$

and G = gravity constant $=66\cdot3\times10^{-9}$ C.G.S.

The gradients $\frac{\partial^2 U}{\partial x \partial z}$ and $\frac{\partial^2 U}{\partial y \partial z}$ at the origin due to this mass are easily shown to be

$$\left(\frac{\partial^2 U}{\partial x \partial z}\right)_0 = \left(\frac{\partial^2 U}{\partial a \partial c}\right)_0 = mG.\frac{3ac}{r^5}$$

$$\left(\frac{\partial^2 U}{\partial y \partial z}\right)_0 = \left(\frac{\partial^2 U}{\partial b \partial c}\right)_0 = mG.\frac{3bc}{r^5}$$

In the case of an attracting mass of finite dimensions, these expressions have to be integrated throughout the mass. For a rectangular block of density ρ having its sides parallel to the co-ordinate planes, the bounding sides being the planes $(x=a_1,\ x=a_2,\ y=b_1,\ y=b_2,\ z=c_1,\ z=c_2)$, we have

$$\left(\frac{\partial^2 U}{\partial x \partial z}\right)_0 = \left(\frac{\partial^2 U}{\partial a \partial c}\right)_0 = \rho G \int_{b_1}^{b_2} db \int_{a_1}^{a_2} da \int_{c_1}^{c_2} \frac{\partial}{\partial c}\left\{\frac{\partial}{\partial a}\left(\frac{1}{r}\right)\right\} dc = \rho G \int_{b_1}^{b_2} db \int_{a_1}^{a_2} \frac{\partial}{\partial a}\left[\frac{1}{r}\right]_{c_1}^{c_2} dc$$

$$= \rho G \log_e \frac{s_{222}\, s_{211}\, s_{121}\, s_{112}}{s_{111}\, s_{122}\, s_{212}\, s_{221}} \quad \text{where } s_{121} = \sqrt{a_1^2+b_2^2+c_1^2}+b_2, \ \&c.$$

Similarly, $$\left(\frac{\partial^2 U}{\partial y \partial z}\right)_0 = \rho G \log_e \frac{t_{222}\, t_{211}\, t_{121}\, t_{112}}{t_{111}\, t_{122}\, t_{212}\, t_{221}}$$

where $t_{121} = \sqrt{a_1^2+b_2^2+c_1^2}+a_1$, &c.

As an example, the gradients due to the north wall density $\rho=1\cdot92$ may be calculated for the point X.

In this case, X being the origin and the axes parallel to the walls, we have

$a_1=1\cdot15\ m$	$b_1=-13$	$c_1=-2\cdot5$
$a_2=+\infty$	$b_2=\infty$	$c_2=+1\cdot07$

Owing to the infinite values of a_2 and b_2, it will be found that the formulæ for $\frac{\partial^2 U}{\partial x \partial z}$ and $\frac{\partial^2 U}{\partial y \partial z}$ reduce to

$$\frac{\partial^2 U}{\partial y \partial z} = \rho G \log_e \frac{t_{112}}{t_{111}},$$

and we have

$$s_{112} = \sqrt{(1{\cdot}15)^2 + 13^2 + (1{\cdot}07)^2} - 13 \qquad s_{111} = \sqrt{(1{\cdot}15)^2 + 13^2 + (2{\cdot}5)^2} - 13$$

$$= 0{\cdot}095 \qquad\qquad = 0{\cdot}288$$

$$\log_{10} s_{112} = \bar{2}{\cdot}9777 \qquad \log_{10} s_{111} = \bar{1}{\cdot}4594$$

$$\log s_{112} = \bar{2}{\cdot}9777$$

$$\log \frac{s_{111}}{s_{112}} = 0{\cdot}4817$$

$$\therefore \frac{\partial^2 U}{\partial x \partial z} = -\rho G \times 2{\cdot}3026 \times 0{\cdot}4817$$

$$= -141{\cdot}1 \times 10^{-9} \text{ C.G.S. units.}$$

Similarly, $$\frac{\partial^2 U}{\partial y \partial z} = -\rho G \times 2{\cdot}3026 \times 0{\cdot}0059$$

$$= -1{\cdot}7 \times 10^{-9} \text{ C.G.S. units.}$$

By similar methods, Table V. has been calculated for stations Z, Y and S, allowing only for the more important local disturbing masses. The results are in reasonable agreement with the observed magnitudes at these stations.

TABLE V.—*Theoretical Gravitational Effects of Laboratory.*

Disturbing Mass.	σ	Station Z.		Station S.		Station Y.	
		$\frac{\partial^2 U}{\partial x \partial z}$	$\frac{\partial^2 U}{\partial y \partial z}$	$\frac{\partial^2 U}{\partial x \partial z}$	$\frac{\partial^2 U}{\partial y \partial z}$	$\frac{\partial^2 U}{\partial x \partial z}$	$\frac{\partial^2 U}{\partial y \partial z}$
North Wall ...	1·92	−40·3	− 1·5	−14·8	− 1·0	−145·6	− 1·6
South Wall ...	1·8	+ 8·0	...	+17·3	+10·0	+ 3·0	+ 1·0
East Wall ...	1·8	...	−10·9	−10·8	−17·9	+ 10·8	−17·9
West Wall ...	1·8	...	+ 9·6	− 3·0	+ 4·0	+ 1·8	+ 4·3
S.E. Pillar ...	2·3	+ 2·7	− 2·5	+15·4	−15·4	+ 2·6	− 0·6
S.W. Pillar ...	2·3	+ 1·3	+ 1·2	...	+ 2·2	+ 1·5	+ 1·2
E. Pillar	2·3	− 1·8	− 4·2	− 3·3	− 1·3	+ 5·2	−15·8
W. Pillar... ...	2·3	− 1·3	+ 3·7	+ 1·0	− 1·0	+ 0·3	+ 1·8
E. Outer Wall ...	1·8	+ 3·5	− 1·0	+ 7·5	+ 3·0	+ 1·7	+ 0·2
Normal Values ...	...	+ 8·0	...	+ 8·0	...	+ 8·0	...
Resultant ...	...	−19·9	− 5·6	+ 9·0	−17·0	−119	− 27

Referred to axes parallel to the walls.

VI. Conclusions.

Although the present results afford no guarantee as to the behaviour of the balance under field conditions, they fully substantiate the claims made for it as regards sensitivity and consistency, and it seems reasonable to suppose that, if due precautions are taken to avoid interference from temperature and radiation disturbing influences, the instrument would function equally well in field operations.

In conclusion we desire to express our thanks to Col. H. G. Lyons, Director of the Science Museum, for the generous way in which he has facilitated this work.

DISCUSSION.

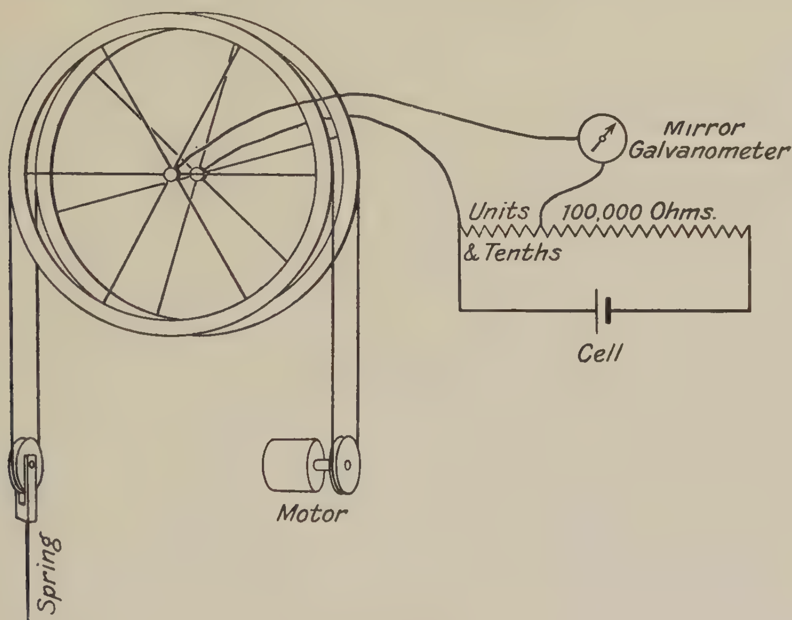
Dr. Alexander Russell said that the Authors' previous Paper on the Eötvös balance had excited considerable interest amongst scientists. The sensibility of the instrument is wonderful and the agreement between theoretical expectations and practical measurements extremely satisfactory.

Mr. E. Lancaster-Jones said that the calculations were based on the assumption that third order derivatives of the gravitational potential could be neglected, but in the experiments described this condition was by no means fulfilled. The close agreement between theoretical and practical results was all the more surprising in view of this fact.

DEMONSTRATION of an Electromagnetic Inductor. By L. F. RICHARDSON, *F.Inst.P.*

THE apparatus shown is intended for teaching purposes, and serves to introduce students at an earlier stage than usual to a quantitative conception of electromagnetic E.M.F. Like the Lorentz apparatus, the present instrument involves a rotating conductor and produces a steady electro-motive force.

Two bicycle wheels are mounted vertically and co-axially, and are driven in opposite directions by a 4-volt motor, the driving band being constituted by an endless wire (stranded picture wire was used), which passes from the motor-pulley over one wheel, under an idle pulley, and back over the other wheel to the motor-



pulley. The electro-motive forces generated by the revolution of the wheels in the earth's field are thus added (the rims of the wheels being electrically connected through the driving wire), and their sum can be tapped from terminals connected to the hubs of the wheels. The speed of the wheels is found by counting the revolutions against a stop-watch, one of the spokes being marked for this purpose, and from this speed and the length of a spoke the E.M.F. can be found in terms of H. It can be compared with that of a Daniell's cell by arranging the latter as the source of current in a potentiometer. The cell is connected in series with a fixed resistance of 100,000 ohms, and with a variable resistance of ohms and tenths, the inductor in series with a galvanometer being shunted across the variable resistance.

Results accurate to 4 per cent. can be obtained with care. Errors due to thermal E.M.F. are eliminated by turning the apparatus through 180 degrees and repeating the observations.

DEMONSTRATION of an Experiment Demonstrating Time-lag in Vision. By F. LL. HOPWOOD, *D.Sc., A.R.C.Sc., F.Inst.P.*

THE experiment* depends upon the fact that the time-lag in visual perception is greater for dimly than for brightly illuminated objects. A pendulum swinging in a plane carries a glow lamp at its lower end. A second glow lamp is fixed immediately below the mid-position of the swinging lamp, and both are viewed with one eye in the ordinary way, while in front of the other eye a metal disc perforated at its centre is so placed as to cut off most of the light reaching that eye. The pendulum then appears to be a conical instead of a plane pendulum, the apparent direction of rotation changing when the disc is transferred from one eye to the other.

This phenomenon is explained by the fact that the image seen by the obstructed eye corresponds to an earlier position of the swinging lamp than does the image seen by the free eye, in consequence of the greater time-lag in the former case. The images seen by the two eyes thus fail to coincide, and as they are combined by the binocular process into a single object, this object appears to be in front of or behind its true position according to the direction of swing and to whether the right or left eye is obstructed.

* *See* C. Pulfrich, Die Naturwissenschaften, Heft 25-27 und 33-38 (1922).

DEMONSTRATION entitled Experiments on the Production of Electromotive Forces by Heating Junctions of Single Metals. By CHAS. R. DARLING, *F.I.C., F.Inst.P., and the Hon.* CHAS. W. STOPFORD

THE experiments shown were devised in order to explain certain effects observed during the progress of a thermo-electric investigation, in which contact had to be made occasionally by a cold metal with a hot piece of the same metal. Large E.M.F.s were noted, which could not be accounted for by the existence of strain in one or other of the pieces joined. In the first experiment a piece of bare copper wire was connected across the terminals of a galvanometer and cut at the middle. One of the cut ends was then heated in a burner, and touched with the cold end, when a large deflection was shown on the galvanometer, which fell to zero on the two ends attaining the same temperature. The "hot-to-cold" E.M.F. was thus shown to depend upon the existence of a temperature gradient at the junction, and was found in iron, nickel, zinc, graphite, and various alloys. In order to maintain such a gradient, two rods were taken, a V-groove being made in the end of one, and a chisel-edge filed on one end of the other. The V-groove was heated by placing a burner near the end of the rod, and the chisel-edge pressed into the groove. Connections were made to the galvanometer by wires of the same material as the rods, and by water-cooling just beyond the chisel-edge a steady gradient was obtained. A constant E.M.F. was generally obtained, which could be measured by a potentiometer. The following results were observed :—

Material.	Groove Temperature (approx.).	Direction of Flow.	E.M.F. (volts).	Resistance of Junction (approx.).
Copper	700°C.	Hot to cold through junction	0·25	40 ohms
Graphite ...	700	Ditto	0·015	50 ,,
Constantan ...	850	Ditto	0·3 (max.)	Variable
Iron	700	Opposite to above	0·024	120 ohms

The E.M.F. in all cases increased progressively with the groove temperature. The high voltages obtained with copper and constantan were noteworthy, and were due to some extent to the coatings of oxide which formed, and this might apply to other oxidisable materials. The result with graphite, however, showed that a coating of oxide was not essential. It was suggested that the magnitude of the E.M.F.s observed rendered the matter of importance, as ordinary thermo-electric effects might easily be overpowered in a circuit where a temperature gradient existed at a joint. It was added that a copper "hot-to-cold" junction served as a wireless detector.

DISCUSSION.

Dr. J. S. G. THOMAS called attention to an account of experiments somewhat similar given by Prof. Carl Benedicks in a lecture at the Institute of Metals in 1920.

Dr. H. BORNS said he hardly understood why Mr. Darling was surprised at his strong thermo-electric forces. When he broke his copper wire with a pair of pincers the two ends of the wire would not be strained equally. The one end of his iron rod (and of his graphite rod) was grooved, the other filed to chisel shape. The one end was heated in a gas flame to about 700°C. ; the

temperature gradients were very steep, and the conditions were favourable to oxidation and other chemical effects, expulsion of gases (from the graphite), and to pronounced heterogeneity.

Mr. F. E. SMITH commented on the extreme difficulty of treating metals in any way without affecting their constitution. In trying to make a junction with E.M.F. as low as 10^{-7} volts he had found it impossible even to cut silver and platinum wires without straining them, and by twisting the wires he obtained a much greater effect. One inference from the omnipresence of thermo-electric voltages is that in the Wheatstone Bridge the galvanometer key ought to be closed before the battery key, contrary to the usual practice.

Dr. D. OWEN said that the voltages obtained appeared to be of the order to be expected from thermo-electric currents at contacts of oxides or sulphides of the metals. Had the authors tried the effect with platinum ?

Dr. J. A. HARKER said that in using the Callendar-Griffiths Bridge some years ago to measure the resistance of copper wire, he had found that if the wire were asymmetrically heated two different values of its resistance were obtained for the two directions of the current through the bridge. The two values drifted further apart with lapse of time. Lord Kelvin regarded the phenomenon as a modified form of the Kelvin effect.

Mr. R. S. WHIPPLE asked whether the E.M.F. obtained is affected by the pressure at the junction. If the effect is chemical, the compression would affect the thickness of any film formed.

Dr. E. H. RAYNER said that thermo-electric currents were formerly dealt with very briefly in the text-books. He would like to know how the subject is now handled in the class-room.

Dr. F. LL. HOPWOOD said that information bearing on the subject of the Demonstration could be found in the published writings of Richardson and Benedicks.

Mr. A. CAMPBELL (communicated) : As the result of experiments on iron and mercury, J. M. Benade (Phys. Rev., p. 199, Vol. 18, 1921) concluded that the effects shown by unsymmetrical heating in solids are due to lack of homogeneity. He found that the effect was absent in mercury.

DEMONSTRATION of the Double Refraction due to Motion of a Vanadium Pentoxide Sol, and Some Applications. By R. H. HUMPHRY, *M.Sc.*

A COLLOIDAL solution of vanadium pentoxide in water has been found by Freundlich, Diesselhorst and Leonhardt (1915) to show double refraction on stirring when it has been aged either artificially or by being allowed to stand. The phenomenon is due to the formation of rod-shaped particles which set themselves in a definite direction when the liquid is caused to move. In linear flow the liquid behaves in the same way as a plate of uniaxal crystal cut parallel to the axis, and placed with the axis parallel to the direction of flow. In convergent light, with the flow along the line of sight, the familiar cross and rings are produced.

The following applications of this double refraction were demonstrated:

(1) Deviation from rectilinear flow owing to the presence of an obstacle. For this purpose the nicol prisms are set in directions perpendicular to and parallel to the direction of the stream.

(2) The thermal convection stream from a wire heated electrically; the nicol prisms are set at 45° to the direction in which it is desired to investigate the stream. These are also the positions of the nicols for (3) and (4).

(3) Efflux of liquid from a jet below the surface.

(4) Disturbance caused by the fall of a liquid globule of nearly the same density through the solution.

(5) Disturbances below the surface due to surface forces when a drop of alcohol is placed on the surface. Only the effect in certain directions could be observed owing to the positions of the nicols.

The colloidal solution of vanadium pentoxide is the most sensitive of all those which show a similar effect. It was kindly prepared by Mr. E. Hatschek in the following way:

Concentrated nitric acid is diluted to 10 times its volume. 0·5 grm. of ammonium vanadate is placed in a mortar and 2 cc. of the dilute acid are added and the mixture stirred. A further 2 cc. of the acid are added and the pentoxide is washed on a filter until it begins to pass through. It is then taken from the filter paper, placed in 200 cc. of distilled water and allowed to stand for 12 hours in a warm place. In 14 days the solution shows excellent striæ between crossed nicols.

DISCUSSION.

Mr. E. HATSCHEK said that the experiments called for exceptional cleanliness as the sol s very sensitive to electrolytes. Aniline blue is interesting in that it gives colour effects; it has a well-marked absorption band, and behaves like a positive crystal to wave-lengths on one side of the band, but like a negative crystal to wave-lengths on the other side.

Mr. R. W. PAUL asked whether the effect of subjecting the liquid to an electrostatic field had been tried.

Mr. J. GUILD said he was not satisfied as to the cause of the double refraction. The colloidal particles are too large to have the effect of molecules, and too small to be regarded as transmitting light after the manner of glass dust. In his reading of ultra-microscopic literature he had come across nothing which suggested a satisfactory explanation. In interpreting the appearances obtained by Prof. Coker's method the greatest caution is necessary. The intensity of the effect of a strain or a streamline depends on its direction, and for certain directions it is impossible to detect a strain at all.

In reply to the discussion Mr. HUMPHRY said that the experiments which were shown were only to be regarded as preliminary, and no interpretation of the observed effects had yet been attempted. It seemed possible by use of this effect to throw more light on streamline problems, and with better apparatus, designed to overcome any tendency towards gelation, useful results might be obtained. The effect of an electric field on the arrangement of the particles had been worked out by Freundlich (Kapillar Chemie, 1922), who also explained the production of the double refraction. It is true that with stationary nicol prisms certain stream lines are accentuated, while others may not appear at all; but this difficulty would be overcome by having rotating nicols. The more delicate means of examining polarised light might show effects which were missed with nicol prisms.

THE PHYSICAL SOCIETY OF LONDON

AND

THE RÖNTGEN SOCIETY.

A DISCUSSION

ON

X-RAY MEASUREMENTS.

Held on February 23, 1923.

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CONTENTS.

PAPERS.

DEMONSTRATIONS.

DISCUSSION ON X-RAY MEASUREMENTS.

Dr. Alexander Russell (in the Chair) said that all present would receive with regret the announcement just received of the death of Prof. W. K. von Röntgen. He spoke of the beneficent services to humanity of the discoverer of X-rays, and asked the meeting to signalise their respect for his memory by standing.

The Chairman then called on Sir William Bragg to introduce the discussion on "X-Ray Measurements."

Sir William Bragg, K.B.E., F.R.S., said that the subject of X-ray measurements was a wide one, but the discussion at this meeting would be mainly confined to the measurement of intensity for the practical purposes of radio-therapy. Methods evolved in recent years make it possible to analyse a heterogeneous beam and measure the wave-length and intensity of its components with extreme accuracy; but although valuable in connection with pure physics, such methods are not suitable for radio-therapy. Here the intensity of the beam as a whole is required, whereas crystal methods introduce effects dependent on the nature of the crystal, such that it would be difficult to synthesise the composition of the original beam from observations made upon its components. The radio-therapeutist must make some assumption as to the distribution of energy amongst these components, and by absorption or otherwise determine the general intensity. In addition to the main beam the scattered radiation has to be considered. It is probably far more considerable than is generally realised, and needs to be taken carefully into account.

THE MEASUREMENT OF X-RAY INTENSITY AND THE NECESSITY FOR AN INTERNATIONAL METHOD.

BY

S. RUSS, *D.Sc., F.Inst.P., Physics Dept., Middlesex Hospital.*

PHYSICISTS rely mainly upon ionisation methods for the measurement of X-ray intensity, and a very large variety of devices is now available by which the intensity of a beam of X-rays can be gauged.

It is important that the instrument should be equally reliable for the measurement of X-rays of different wave-lengths. This is not at all an easy matter because of the complicated phenomena which appear when a primary beam of X-rays enters an absorbing medium. Let us consider a beam of X-rays of intensity I_0 and wave-length λ_0 entering an air space of length x (Fig. 1). The intensity is defined as the amount of energy incident per second upon unit area placed normal to the rays.

On entering this space some of the radiation is scattered, some is absorbed, and the remainder is transmitted. We may write this as follows :—

$$I_0 = sI_0 + s'I_0 + q_0 + I_0 e^{-\mu_0 x},$$

where s and s' are the scattering coefficients in the backward and forward directions, q_0 is the quantity of energy quenched per second in the air space and causing ionisa-

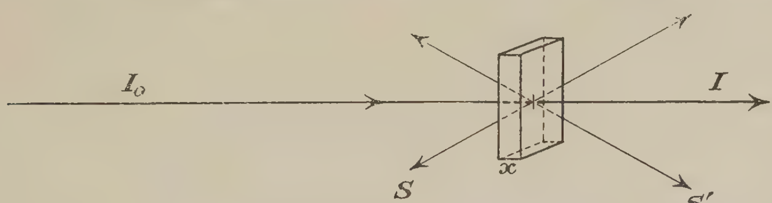

FIG. 1.—INTENSITY EFFECT METER.

tion, and the last term is the fraction transmitted, μ_0 being the absorption coefficient of the medium for the wave-length specified ; heating effects are neglected here.

Consider now a beam of different wave-length λ_1 and of intensity I_1, then, as before, we have—

$$I_1 = s_1 I_1 + s_1' I_1 + q_1 + I_1 e^{-\mu_1 x}.$$

Now it is possible experimentally to arrange that an equal intensity of ionisation in the meter is produced by these two beams, so that $q_0 = q_1$.

Hence, for this particular case we may say

$$\frac{I_1}{I_0} = \frac{1 - e^{-\mu_0 x} - (s + s').}{1 - e^{-\mu_1 x} - (s_1 + s_1').}$$

Now if the terms involving the absorption coefficients are more significant than those involving the scattering coefficients—and this can be arranged experimentally —we may write

$$\frac{I_1}{I_0} = \frac{1 - e^{-\mu_0 x}}{1 - e^{-\mu_1 x}}.$$

S 2

The above expression shows that if we wish to compare the intensities of two beams of different wave-lengths, then this can only be done if we know the coefficients of absorption of the medium.

It may be noted here that even if measurements are restricted to beams of X-rays of a single wave-length, the ordinary ionisation chambers can hardly be said to measure the intensity because the bulk of the radiation is transmitted through

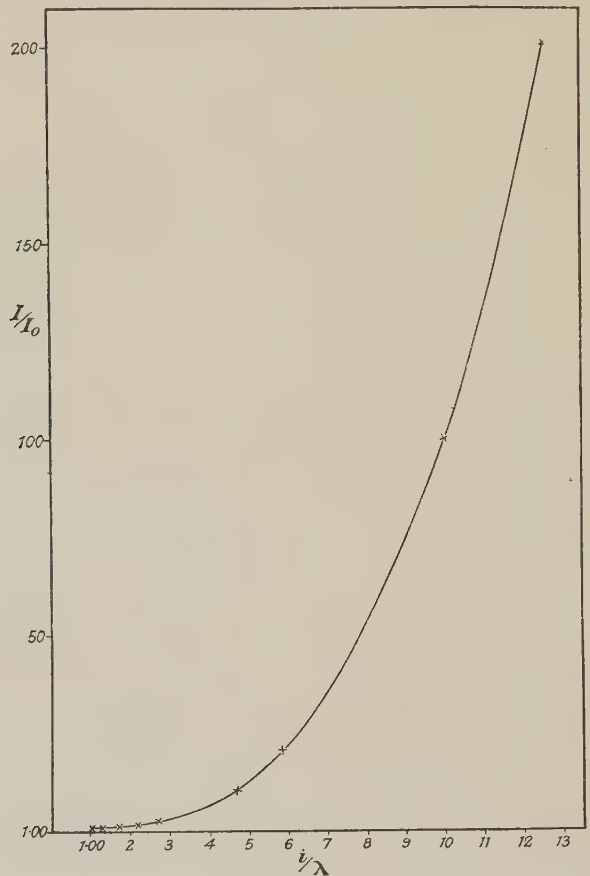

FIG. 2.

them, and so they should perhaps be more correctly looked upon as intensity-effect meters.

E. A. Owen has shown that a simple relation holds between the wave-length of a beam of X-rays and the absorption coefficient in a medium, provided that no "characteristic" radiation plays a part in the process of absorption. This relation is $\mu \propto \lambda^{5/2}$, and subsequent work has shown that $\mu \propto \lambda^3$ is of even more general application. By means of this last expression we can express the ratio I_1/I_0 in terms of the wave-lengths, and the graph of Fig. 2 shows how this ratio increases as the

wave-length is shortened. The range of wave-length includes practically the whole extent of the radiation which is used in medical radiology.

The simple relationship outlined is only true under certain experimental conditions. They are, however, not too exacting to be practical. Perhaps the most important thing to bear in mind in designing an ionisation chamber suitable for comparisons of the intensity of different wave-lengths is that any secondary radiation produced in the instrument should not vitiate the results. There seems to be very little doubt that the simple air gap is the best for this purpose, for directly the rays are allowed to strike the solid walls of the chamber or the electrodes, secondary

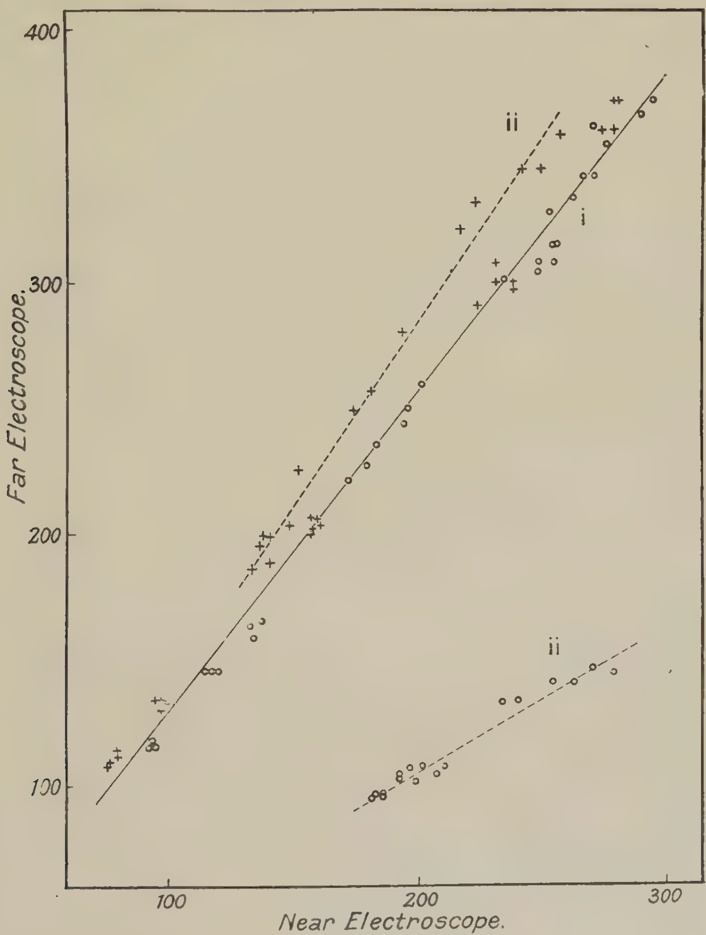

Fig. 3.

radiation may be produced by one wave-length but not by another, and so in this way true measurements are not obtained.

As an example of this, Fig. 3 shows two sets of experimental results, which were obtained in the following way :—

An X-ray tube was set up in such a way that it could send a vertical beam to

a near electroscope (40 cm.) and a horizontal one to a far electroscope (4 metres). In experiment No. 1 the near electroscope consisted of a simple air gap cut transversely in a lead cylinder, the electrodes being set so that the vertical beam of X-rays just missed them. The ionisation in this gap was measured by means of a gold leaf connected electrically to one of the electrodes. The far electroscope consisted of an ordinary gold leaf electroscope made of lead fitted with a central brass stalk holding the leaf and a window of thin aluminium to allow the X-rays to enter the instrument.

Simultaneous readings were obtained upon the two electroscopes with (1) a beam of " soft " X-rays and (2) a beam of " hard " rays.

It was easy to arrange that the near electroscope gave identical readings for the " hard " and " soft " rays—but when this was the case the reading of the far electroscope was considerably greater with " hard " than with " soft " rays until a diaphragm was used to cut down the radiation so that identical readings were also obtained on the far electroscope with " hard " and " soft " rays. This is shewn by the single full line *I* going through the crosses (" soft " X-rays) and circles (" hard " X-rays) (Fig. 3). In experiment No. 2 the only change made was in the near electroscope. A paper cylinder 3·5 cm. long and 1·5 cm. diameter, fitted with a central electrode of aluminium, was substituted for the simple air-gap. Exactly the same thing was now carried out with this arrangement, and the two sets of experimental values show that the composition of this ionisation chamber has greatly favoured the soft type of radiation. It will be seen that in order to get an equality of readings with " hard " and " soft " X-rays on this ionisation vessel it was necessary to use a beam of " hard " rays about $2\frac{1}{2}$ times as intense as would have been sufficient had the simple air-gap been used.

Conclusion.

Little remains for me to say about the necessity which exists for a method of comparing and measuring the intensities of beams of X-rays of different wave-lengths.

In the practice of medical radiology a variety of indicators is used. Each has its use within restricted limits, but no one of them can at the present time be looked upon with complete confidence to give the information desired.

In purely scientific work, each one puts up some method which serves the purpose in hand, but it is almost impossible at present for any research centre to make use of the data given by other centres. For these reasons I hope that this combined meeting of the Physical and Röntgen Societies (February 23, 1923) may mark the beginning of an attempt to set up an unequivocal method of comparing and measuring the intensities of beams of X-rays of different wave-lengths, and that it may then be possible to specify some quantity which shall be looked upon as an international unit of X-ray energy.

THE QUALITY OF X-RAYS PRODUCED BY VARIOUS HIGH-TENSION GENERATORS AND AN INCANDESCENT CATHODE TUBE.

BY

F. J. HARLOW, *B.Sc., F.Inst.P., A.R.C.Sc., and* E. J. EVANS, *B.Sc.*

ABSTRACT.

1. Measurements of the absorption in aluminium have been made of the X-radiation emitted by an incandescent cathode X-ray tube excited by various forms of high-tension generator. The results show that after traversing 1 cm. of aluminium the coefficient of absorption in aluminium becomes approximately constant.

2. The radiation transmitted through 1 cm. of aluminium is defined as the "end-radiation," and it is shown that for the same value of equivalent spark-gap different machines give different qualities of "end-radiation."

The induction coil is shown to give different results at the same equivalent spark-gap with different lengths of interrupter contact.

3. Curves showing the observed coefficient of absorption of the "end-radiation" plotted against peak voltage deduced from the equivalent spark-gap are different for different machines, and for the induction coil operated with various lengths of interrupter contact. It is consequently deduced that measurements of equivalent spark-gap do not provide a measure of the hardness of the "end-radiation."

4. The important result is obtained that the absorption curves for the various machines under conditions of the same quality of "end-radiation" are indistinguishable, from which it follows that under these conditions X-radiation is produced in which the intensity distribution in the spectrum is the same for all the machines. Somewhat similar results have been obtained by A. Dauvillier using the X-ray spectrometer. The same result obtains with the induction coil operated with various lengths of interrupter contact.

5. A practical method of measuring the general quality of X-radiation is suggested.

6. The discrepancy between the result obtained with the Wimshurst machine and that obtained by A. Dauvillier with an arrangement producing constant potential led to the suggestion that the output of the former might be of an intermittent character. Experiments are described showing that intermittent X-radiation is produced when the Wimshurst machine is employed as the high-tension generator. A further investigation of this phenomenon is in progress.

INTRODUCTION.

THE relative advantages of various types of high-tension generator in the production of X-rays have been the subject of considerable discussion by radiologists and others during recent years. The following is an account of experiments carried out by the authors in an attempt to elucidate some of the phenomena hitherto unexplained. Reference to the work has already been made by one of the authors in the discussion on the subject* at the joint meeting of the Institution of Electrical Engineers, the Royal Society of Medicine, and the Röntgen Society, held in February, 1920. Publication of the complete results has been delayed pending further investigation with the Wimshurst machine which appeared desirable.

The high-tension generators available for the experiments were the induction

* *See* Journal Inst. Elect. Eng., Vol. 58, No. 294, August (1920).

coil, two types of closed magnetic circuit high-tension transformer and the Wimshurst machine. These machines are largely used in the production of X-rays in medical and industrial practice.

At the time the work was undertaken the opinion was generally held among radiologists that high-tension interrupterless transformers, although possessing many advantages in practice, were, when operated under similar conditions as to spark-gap and milli-amperage, less productive than the induction coil, of rays of the quality most useful in radiography.

The authors of the present Paper considered that this might be due to a marked difference in the distribution of intensity among the various wave-lengths due to the difference in potential and current wave forms given by the two types of machine.

Ulrey* has shown that the X-ray output is proportional to the square of the voltage through which the generating cathode rays fall; and the higher the voltage the harder is the radiation produced. The distribution of intensity among the various wave-lengths of the spectrum should, therefore, it seems, depend upon the potential and current wave forms, and also upon the phase difference, if such exists, between current and potential.† A complete investigation of the problem requires the taking of oscillograms of potential and current and the correlation of these with the observed distribution of X-ray intensity.

In the absence of a suitable oscillograph and of an X-ray spectroscope this could not be undertaken, but it appeared that an examination of curves of absorption in aluminium for the radiation produced by the various machines might contribute towards the solution of the ploblem.

Apparatus and Experimental Arrangements.

Absorption curves in aluminium were obtained by means of the apparatus shown in Fig. 1 (*a*).

A is a heavily protected tube box containing the X-ray tube with an adjustable rectangular diaphragm at *D*.

B is a lead plate having a rectangular opening and also a shelf fixed at (*F*) to hold aluminium filters.

C is an ionisation chamber, the plate *P* being connected to one pair of quadrants of a Dolezalek electrometer.

All the points marked *E* were connected to earth, while the other wire connections were insulated by pieces of ebonite marked *I*.

The X-rays were passed through different thicknesses of aluminium and the ionisation currents produced in the ionisation chamber by the transmitted rays were measured.

In order to reduce to a minimum the effects of secondary radiation, either scattered or fluorescent, the distances between the diaphragm, aluminium strips and ionisation chamber were made large.

Different methods of measuring ionisation currents were tried, and the most suitable for such large intensities was found to be the steady deflection method as used by Bronson.‡

* Physical Review, p. 407, May (1918).

† Dauvillier, Revue Générale de l'Electricité. Mars (1917).

‡ Phil. Mag., pp. 143-146, January (1906).

This method consists in connecting to earth through a high resistance the pair of electrometer quadrants receiving the ionisation current. The quadrants thus become charged to a potential such that the rate of leak to earth is equal to the charging current ; and a steady deflection of the needle is obtained dependent upon and proportional to the ionisation current. The resistance employed was about 10^{10} ohms, and consisted in a mixture of xylol and alcohol contained in a glass U-tube (see Fig. 1 (*b*)).

The steady deflection method of using the electrometer has the advantage in work covering a wide range of ionisation current in that the sensitiveness can be adjusted by varying the value of the high resistance ; provision for which was made as indicated in the diagram by a number of platinum terminals at various points along the limbs of the U-tube.

The X-ray tube employed was a Coolidge tube of the self-rectifying radiator

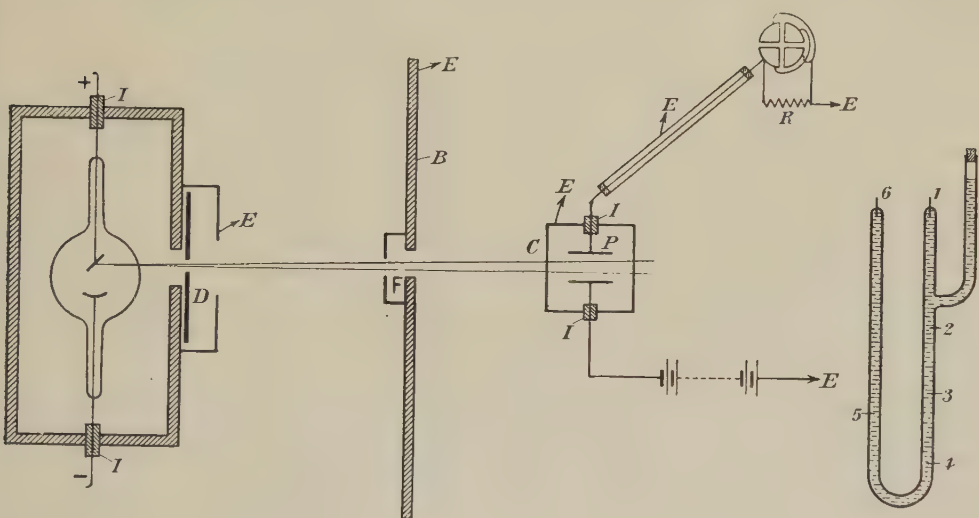

FIG. 1(*a*). FIG. 1(*b*).

type, the cathode filament of which was heated by an insulated battery in the usual manner.

The high-tension generators available for the purpose of the investigation were as follows :—

(*a*) Induction coil, 16 inch bi-sectional, with mercury jet interrupter.
(*b*) Small high-tension oil transformer, U.S. Army pattern.
(*c*) Large high-tension transformer, Snook pattern.
(*d*) Large 20 plate sectorless Wimshurst machine, plates 22 ins. diameter.

Our thanks are due to Sir Archibald Reid, K.B.E., to the Army Medical Department, War Office, to the Medical Supply Association and to Messrs. Newton & Wright, Ltd., for their kind assistance in placing apparatus at our disposal.

In order to excite the X-ray tube by the various machines under similar conditions of equivalent spark-gap, spheres of diameter 5 cm. were employed, and in every case it was found possible to arrange that throughout an experiment the

equivalent spark-gap should be maintained sufficiently constant to obtain steady and consistent readings of the electrometer. The conditions were adjusted so that during a run an occasional spark passed between the spheres.

Experimental Results.

A typical set of logarithmic absorption curves as obtained with the various types of high-tension generator for different spark-gap values is shown in Fig. 2. For each curve the initial intensity was made the same by adjustment of the diaphragm, other intensities being expressed as percentages of the initial intensity; the slope of the logarithmic absorption curve is a measure of the coefficient of absorption, and it will be seen that the radiation after passing through 1 cm. of aluminium is approximately of a homogeneous character as measured by its coefficient of absorption (μ), a fact already established by other workers—*e.g.*, by Russ* and by Rutherford† and others.

The radiation remaining after constancy of coefficient of absorption is reached

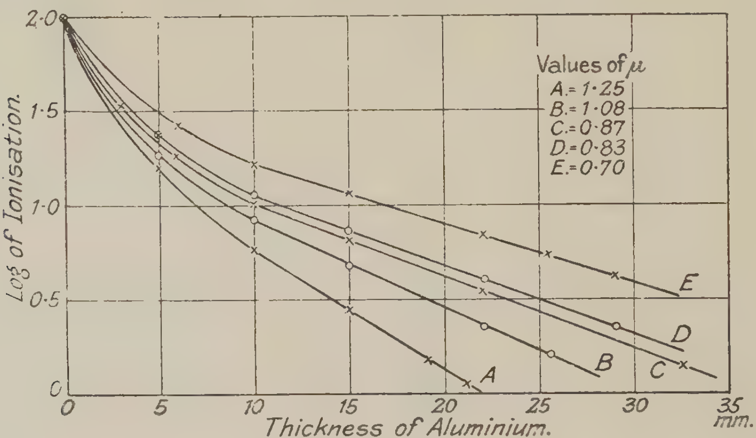

Fig. 2.

is usually spoken of as the " end-radiation,' and for the sake of clearness of description it is convenient to define the " end-radiation " as that remaining after absorption by 1 cm. of aluminium.

Comparison of Absorption Curves for the Different Machines under Conditions of Similar Equivalent Spark-Gap.

In Figs. 3, 4 and 5 are shown three different sets of logarithmic absorption curves selected from a large number. Each set of curves corresponds to a definite length of equivalent spark-gap, the different curves being obtained with the various machines. The stated voltages are calculated from the lengths of equivalent spark-gap by means of the tables prepared by Kaye.‡ Fig. 3 shows two curves at 67 k.v.

* J. R. S., April (1915).
† P. M., September (1915).
‡ *See* Cantor Lectures, R. S. A., March (1921).

for the induction coil and Snook transformer. Fig. 4 shows five curves at 78 k.v. one for each of all the machines employed. In this case the curves for the induction coil (used with a long contact in the interrupter), and the Snook transformer co-

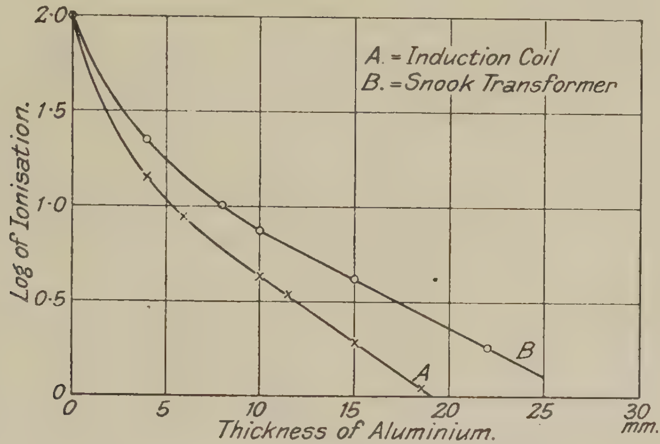

FIG. 3.

incide. Fig. 5 shows three curves at 86 k.v. taken with the Snook transformer, the Wimshurst machine and the induction coil.

It appears to be fairly generally assumed in X-ray practice that whatever type of machine is employed or under whatever conditions any one type of machine may

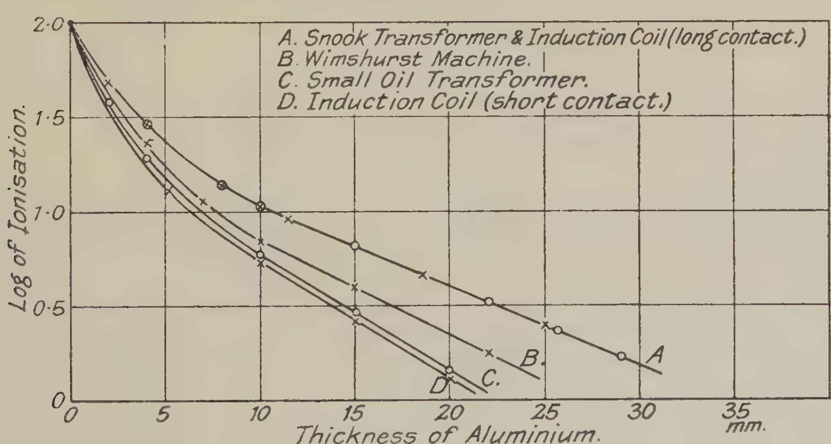

FIG. 4.

be employed, if the equivalent spark-gap is the same the same quality of radiation is produced. In radiography as a rule, it is the " end-radiation " which reaches the photographic plate and which consequently is the effective radiation so that it will be the " end-radiation " which is assumed to be the same for the same equivalent

spark-gap. An examination of the curves in Figs. 3, 4 and 5 shows that for the same equivalent spark-gap the different machines give very different qualities of "end-radiation." Further, curves A and D (Fig. 4) were both obtained with the induction coil under similar conditions except for length of interrupter contact. With the longer contact the rays were more penetrating.

It was anticipated when the research was undertaken that a set of curves obtained at the same equivalent spark-gap would show considerable differences in their initial portions, but that the "end-radiation" would be of the same quality (same slope of logarithmic absorption curve). Had this been the case we purposed comparing the suitability of the various machines for radiographic purposes by ascertaining in each case the ratio of the intensity of the "end-radiation" to that of the initial radiation, and comparing the ratios obtained with the various machines. Those machines yielding small percentages of "end-radiation" would obviously not be so useful for radiographic purposes as those yielding larger percentages, as the

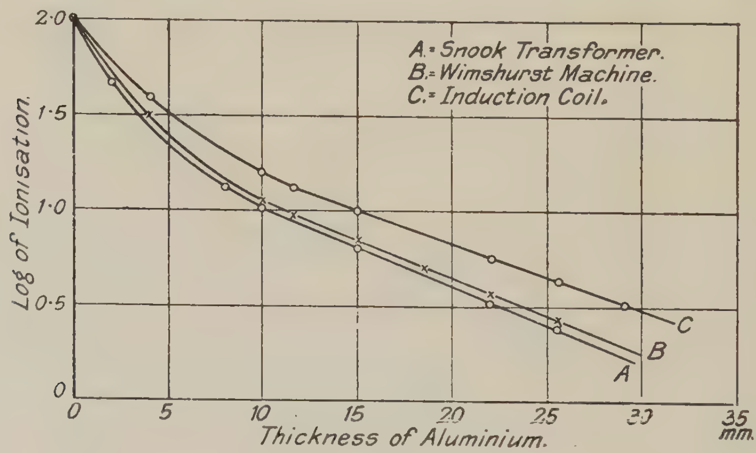

FIG. 5.

softer radiation, being absorbed in the object to be radiographed, is of no radiographic value. However, as the various machines gave different qualities of "end-radiation" for the same equivalent spark-gap no useful purpose would be served by comparing the relative percentage amounts of "end-radiation" present in the initial heterogeneous beams.

Equivalent Spark-Gap and Hardness of "End-Radiation."

The curves in Fig. 6 show for each machine the way in which the coefficient of absorption in aluminium of the "end-radiation" varies with the peak voltage as calculated from the equivalent spark-gap. The curves for the various machines are distinctive, variations in hardness being as a rule very considerable for the same spark-gap, as has already been pointed out in connection with the curves of Figs. 3, 4 and 5.

It will be seen that the curve "a" for the Snook transformer crosses one of those for the induction coil curve "b"; this means that for the lower values of equivalent spark-gap the induction coil gave softer radiation than the transformer, the reverse

being true for the larger values of gap. Results at one value of equivalent spark-gap only, namely, 78 k.v., represented by point "e," were obtained with the small oil transformer without rectifier. The hardness in this case is less than for the Snook transformer employing a rectifier.

It is possible that this latter result is due to the inverse voltage being greater than the direct through the suppression of the inverse current, and when the tube acts as rectifier the spark-gap will be that equivalent to the inverse voltage rather than to the direct.

By varying the conditions of excitation of the coil, viz., by shortening the interrupter contact a different curve "*d*" was obtained. Curve "*c*" shows the results obtained with the Wimshurst machine.

The experiments appear therefore to establish quite clearly and definitely that, when operated under conditions of similar equivalent spark-gap, different forms of high-tension generator, when employed to excite an incandescent cathode X-ray tube, produce different qualities of effective or "end-radiation"; similarly, if the length of contact in the interrupter of an induction coil be varied and the current adjusted to produce the same equivalent spark-gap a different quality of "end-

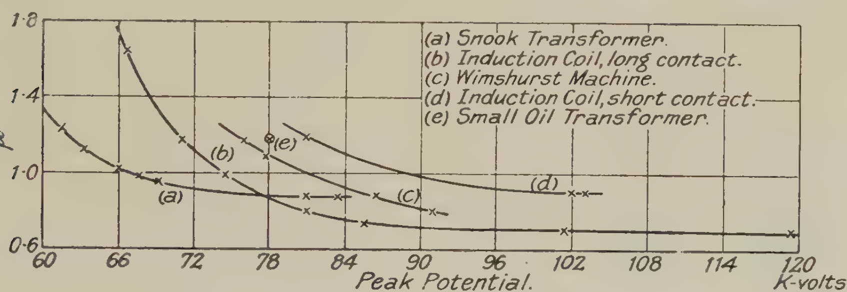

FIG. 6.

radiation" results. The equivalent spark-gap does not therefore give a measure of the relative hardness of "end-radiation" produced by different machines, neither does it give a measure of the relative hardness of "end-radiation" produced by the induction coil under different conditions of excitation.

Comparison of Absorption Curves for the Different Machines under Conditions of Similar Hardness of "End-Radiation."

In view of the above procedure failing to provide a satisfactory basis for comparing the performance of the machines, it appeared desirable to examine the results with a view to comparing the percentage intensities of "end-radiation" under conditions such that all the machines were producing the same quality of "end-radiation" (*i.e.*, giving the same slope of logarithmic absorption curve after absorption by 1 cm. of aluminium).

In Table I. are shown under conditions of similar hardness of "end-radiation" the intensities of "end-radiation" expressed as percentages of initial radiation. This condition may be attained by a suitable choice of equivalent spark-gap. The

results are shown for several different hardnesses of "end-radiation," the hardness being indicated by the coefficient of absorption in aluminium.

TABLE I.

Coefficient of absorption in aluminium.	Per cent. Intensity of "End-Radiation."				
	Small oil transformer.	Snook transformer.	Induction coil (long contact).	Induction coil (short) contact).	Wimshurst machine.
1·11 to 1·18	6·1	5·9	5·8	5·7	6·3
1·03	...	8·3	8·2	...	7·8
0·86	...	11·7	11·0	...	11·5
0·83	...	11·9	12·0	...	...
0·81	...	12·3	12·4	...	...
0·77	...	...	16·6	...	16·9

It will be observed that within the limits of experimental error the percentage intensity of "end-radiation" is the same for all machines. Further when the absorption curves are plotted for the same hardness of "end-radiation," they are indistinguishable.

A typical curve is shown in Fig. 7, the experimental data for which are given in

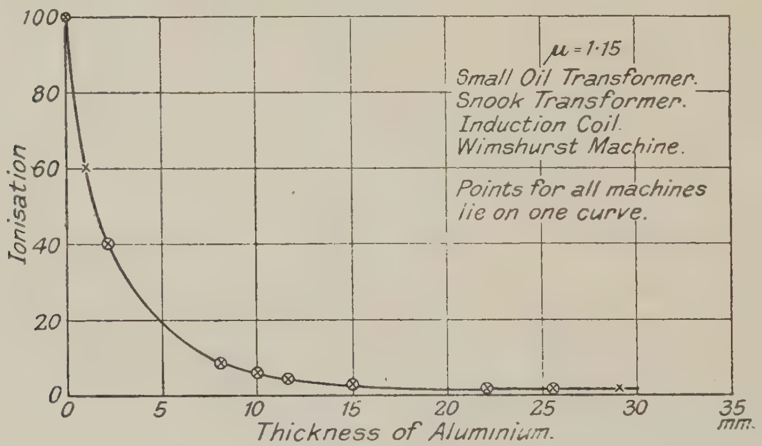

FIG. 7.

Table II.(A). Other experimental data giving indistinguishable curves are set out in Table II.(B), (C) and (D).

The result given on following page is of considerable technical importance. It shows that by a suitable adjustment of the conditions of equivalent spark-gap it is possible to obtain the same quality, not only of the "end-radiation," but of the initial radiation whichever machine is employed; or, in the case of the induction coil the same quality of radiation with different lengths of interrupter contact.

In addition the result appears to indicate that the distribution of X-ray intensity in the heterogeneous beam of radiation is characteristic of the X-ray tube rather than of the potential wave-form of the high-tension machine.

TABLE II.—*Radiation Intensities after Filtration expressed as percentages of Intensities of Unabsorbed Radiation.*

(Same hardness of " end-radiation " for all machines.)

Set No.	Type of machine.	μ	P.D. in k.v.	Percentage intensity of radiation after filtration. Thickness of aluminium in mm. 0	1	2	4	6	8	10	11·5	15	18·5	22	25·5	29	32·5	34·25
A	Oil transformer ...	1·13	78	100	60	41	22·1	13	8·6	6·1	50	2·9	...	1·2	0·8	...	0·5	0·3
	Snook transformer	1·15	62	100	...	...	22	...	...	5·9	...	2·9	...	1·2	...	0·6	...	...
	Induction coil (long contact) ...	1·18	71	100	...	...	...	...	...	5·8	4·8	2·7	...	1·2	0·9	...	...	...
	Induction coil (short contact) ...	1·18	80	100	...	...	...	...	...	5·7	4·8	2·65	...	1·15	0·85	...	...	...
	Wimshurst	1·11	76	100	...	41	27	...	8·7	6·3	5·2	3·2	2·4	1·3	...	...	...	...

Set No.	Type of machine.	μ	P.D. in k.v.	Thickness of aluminium in mm. 0	4	5	8	10	11·5	15	18·5	22	25·5
B	Snook transformer	1·03	66	100	...	21	...	8·3	...	4·3	3·0	2·1	1·4
	Induction coil (long contact) ...	1·06	73	100	...	...	...	8·2	6·1	4·1	3·0	1·9	1·3
	Wimshurst	1·07	77	100	27	...	14	7·8	...	3·6	2·8	1·8	1·3

Set No.	Type of machine.	μ	P.D. in k.v.	Thickness of aluminium in mm. 0	2	4	6	8	10	11·5	15	18·5	22	25·5	29	32·5
C	Snook transformer	0·86	79·5	100	47·3	28	18	14	11·7	9·2	6·3	...	3·2	2·3	...	1·4
	Induction coil (long contact) ...	0·87	77·5	100	...	...	...	...	11	...	6·5	4·8	3·4	2·5	1·9	...
	Wimshurst	0·85	85	100	49	29	...	14	11·5	8·9	6·6	4·9	3·5	2·6	1·9	...

Set No.	Type of machine.	μ	P.D. in k.v.	Thickness of aluminium in mm. 0	2	4	8	10	11·5	15	18·5	22
D	Induction coil (long contact) ...	0·78	82	100	...	...	...	16·6	...	12	...	6·9
	Snook transformer	0·76	90	100	60	41	21	16·9	13	10	7·9	...

QUALITY OF X-RADIATION AND CURRENT THROUGH X-RAY TUBE.

If absorption curves are plotted for a given machine at constant equivalent spark-gap but for various initial intensities of radiation (produced by varying the filament heating current of the X-Ray tube), the general quality of the radiation remains the same. Fig. 8 shows four logarithmic absorption curves taken for the same equivalent spark-gap and with various currents passing through the X-Ray tube.

It will be observed that the curves are parallel indicating similarity of quality. It follows, therefore, that not only can the same quality of radiation be obtained

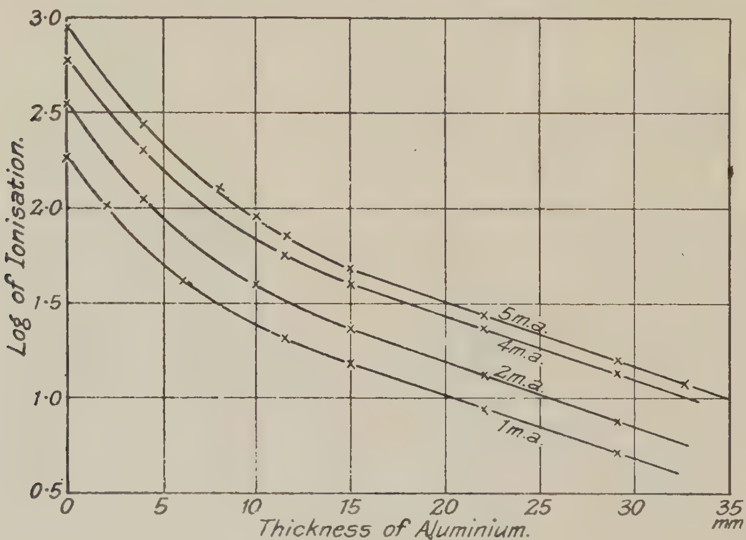

FIG. 8.

for the various machines by a suitable adjustment of the conditions, but that by adjustment of the current passing through the tube the same intensity may also be obtained.

DISCUSSION OF EXPERIMENTAL RESULTS AND COMPARISON WITH THOSE OF OTHER INVESTIGATORS.

After the completion of the experiments described in the present Paper, results of an investigation along somewhat similar lines were published by A. Dauvillier,* who employed the X-ray spectrometer, which permits of a much more thorough analysis of the quality of radiation emitted. As sources of high-tension current he employed the induction coil, the closed-magnetic circuit high-tension transformer, and for constant potential a special arrangement consisting of an induction coil, a valve and a condenser charged by the induction coil through the valve. To secure equality of peak potential, Dauvillier employed the method of arranging that the shortest wave length in the spectrum is the same in each case. By reason of the quantum relationship $hc/\lambda = Ve$ this would appear definitely to provide for equality

* Ann. de Physique, Tome 21, Mars-Avril (1920).

of peak and constant potentials. Dauvillier found that the induction coil and the transformer gave, for the same peak potential, similar spectral curves, *i.e.*, curves showing similar distributions of intensity among the various wave lengths. This result was obtained at 46 kv. and also at 95 kv. On the other hand, with the constant potential the spectral curve was relatively richer in intensity for the rays of shorter wave-length.

Comparison of Results for Coil and Transformer.

Dauvillier's procedure with the coil and the transformer of adjusting the conditions until the shortest wave-length was the same in each case appears to correspond precisely to our selection of conditions giving the same quality of "end-radiation." Dauvillier's observations thus agree with ours in showing that under suitable conditions both the induction coil and the transformer produce radiation giving similar spectral curves. Further investigations, however, appear to be necessary to ascertain the reason why the values of the equivalent spark-gap, which were measured with care under ordinary practical conditions, are different for the two machines.

Dauvillier* recommends the measurement of the shortest wave-length in the X-ray spectrum as the most accurate method of measuring peak potential, and has in consequence, by an extended series of observations, calibrated both sphere and point spark-gaps for peak potentials produced in various ways. The obtaining of concordant results appears to have been a matter of considerable difficulty. When brass spheres were used special precautions had to be taken to maintain them in a highly polished state and, in addition, it was found necessary to include in the spark-gap circuit a resistance of distilled water of a million ohms to prevent the formation of arcs. With these precautions the calibration curves obtained with the coil, high-tension transformer, and apparatus for constant potential showed a fair agreement. They differed, however, considerably above 75 kv. from the curve obtained with the unrectified transformer, the peak voltages for which were not obtained by the X-ray method, but by calculation from the R.M.S. values measured by an electrostatic voltmeter. This divergence is attributed by Dauvillier to the effect upon the value of the spark-gap of ultra-violet rays produced by brush discharges from the high-tension leads of the X-ray tube circuit. A similar effect probably operated in our experiments. It was not found necessary, however, in our experiments to take such special precautions as those described by Dauvillier in order to obtain the reasonably smooth curves shown in Fig. 6.

The considerable differences obtained in our experiments with the various machines can scarcely be attributed simply to variations arising from contamination of the surfaces of the spheres, and it is considered that some other explanation must be looked for. In this connection it is of interest to note that in the earlier publication† of Dauvillier's reference is made to the fact that some of the oscillographic records indicate a small phase difference between current and potential arising presumably through the electrostatic capacity of the tube which, although small, would be sufficient with a peaked wave form to modify considerably the character of the radiation produced.

* Loc. cit.

† Dauvillier, Revue Générale de l'Electricité, Mars (1917).

It may be mentioned that manufacturers of X-ray apparatus have observed that tube boxes fitted with earth-connected metal modify the X-ray output. It is conceivable that this may be due to the increased capacity causing a phase difference between the potential and the current. Such a capacity effect would obviously be different with different machines and might account for the variable hardness of " end-radiation " obtained in our experiments when the different machines are run under conditions of similar equivalent spark-gap. It should be observed that the tube-box employed was heavily protected with earth-connected sheet lead and in addition a large metal diaphragm was employed (Fig. 1). Observations to test this suggested explanation would require careful simultaneous oscillographic records of current and potential. These, however, we have been unable to make.

Results at Constant Potential.

In a brief account of researches on the spectral curves obtained with a generator at constant potential, A. W. Hull* points out that, in his opinion, it is possible to find a voltage and current for constant potential which will give a spectrum practically the same as that given by the transformer at a different definite voltage and current. The two similar spectral curves reproduced in the Paper are for constant and peak voltages of the same value, viz., 70 kv., the currents being 2 and 3 milliamperes respectively. Assuming the Wimshurst machine to generate current at constant potential, the obtaining in our experiments of similar absorption curves with the Wimshurst machine and the transformer lends support to the view expressed by Hull (which, however, does not appear to be supported by appreciable experimental evidence). As already mentioned, Dauvillier's experiments at constant potential have given a different result, viz., a spectral curve relatively richer in rays of shorter wave-length. It appeared, therefore, to the authors of the present Paper desirable to make further observations with the Wimshurst machine, and, as will be seen in a later section, experimental evidence has been obtained that the X-ray emission with the Wimshurst machine is intermittent in character. Under these circumstances the results obtained by Hull and Dauvillier are scarcely comparable with those obtained by us with the Wimhurst machine.

In connection with the above results it is interesting to notice a further result obtained by Dauvillier, who extended his observations to the gas form of X-ray tube. With a constant potential applied to the gas tube Dauvillier has shown that the discharge is intermittent.† In his later Paper‡ he shows that this gives rise to spectral curves practically indistinguishable from those obtained with the induction coil or with the transformer.

There is therefore both in our researches and in those of Dauvillier considerable experimental evidence that the application of an intermittent potential to an X-ray tube produces similar spectral curves under suitable conditions, whatever the wave form of the discharge.

It is not clear why this should be so, and, as already explained, it was expected when the present research was undertaken that differences in the spectral curves would be shown for the various machines.

* Amer. Jour. Roert (1915).
† Dauvillier, Revue Générale de l'Electricité, Mars (1917)
‡ Ann. de Physique, Tome 21, Mars-Avril (1920).

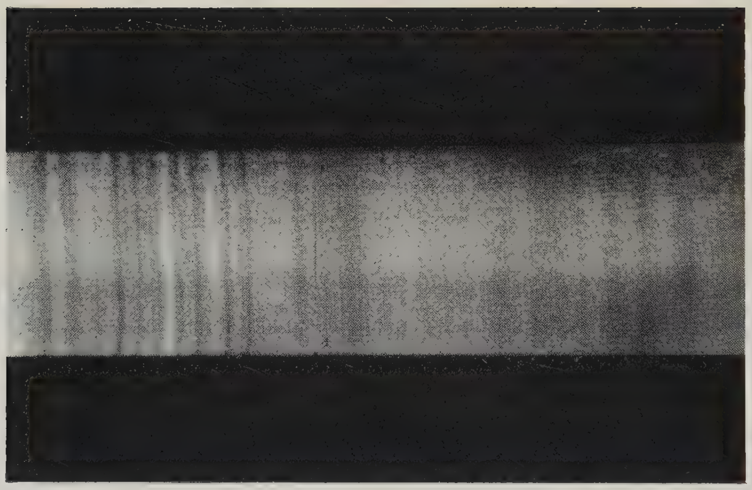

FIG. 10.—INTERMITTENCY OF DISCHARGE. (WIMSHURST MACHINE, COOLIDGE TUBE.)

[*To face page* 21D.

Criticism of the Absorption Method.

Mention should be made of the criticism of the absorption method given in Dauvillier's Paper (loc. cit.). The X-ray spectrometer method is admittedly a much more powerful method of analysis, capable of giving more detailed information concerning the quality of radiation emitted. It is, however, justifiable to make deductions of a general character from the results obtained by absorption method, as the pioneer work of Barkla and others has shown. In our experience the statement made by Dauvillier that a small experimental error makes a considerable alteration in the position of a point when plotted on the graph is not in accordance with fact.

It is disproved by the facility with which a smooth curve can be obtained, in spite of the several factors contributing to the intensity of radiation. We consider rather that for the harder radiations, owing to a high proportion of the absorption being due to scattering, the co-efficient for which varies little with wave length, the method lacks somewhat in sensitiveness as compared with the method of the X-ray spectrometer.

The curves of Fig. 2 show, however, that in spite of this consideration, the change with voltage in the coefficient of absorption of the "end-radiation" is considerable, and on this account the deductions we have made when similar absorption curves have been obtained under various conditions are considered to be justifiable.

Further Investigations with the Wimshurst Machine.

As already mentioned, the discrepancy between the results obtained with the Wimshurst machine and those obtained by Dauvillier at constant potential, rendered desirable an investigation into the character of the discharge from the Wimshurst machine. In the absence of an oscillograph to test the constancy of potential, the intermittency of X-ray emission was tested by a photographic method.

The apparatus is shown in Fig. 9, and consisted in a tunnelled photographic plate carrier C arranged so that the latter passed, at a rate which could be regulated, in front of a narrow slit (S) cut in the lead face A of the tunnel. The tunnel was arranged vertically, the carrier being counter-weighted, so that its speed in front of the slit could be regulated by adjustment of the weight W. For the purpose of ascertaining the speed of the plate a vibrating strip of known frequency fitted with a camel hair brush was arranged at the back of the tunnel. From the curve traced out on a paper strip gummed to the plate the speed could be determined. The remarkable result shown in Fig. 10 was obtained confirming the predicted intermittency, the frequency of which was found to be of the order of 15 per second. An experimental investigation of the cause of this intermittency is in progress by one of us (E. J. Evans). The discrepancy between the results obtained by Dauvillier at constant potential and those obtained in our experiments with the Wimshurst machine may thus be due to the fact that the current given by the Wimshurst machine is not generated at constant potential. A possible explanation is that the intermittency results from the collection of the charges from the plates of the machine by the phenomenon of the brush discharge for, as already pointed out, Dauvillier has shown that under certain conditions discharge through gases is of an intermittent character, even when a constant potential is applied. If the discharge

at the collectors is of this character the potential applied to the X-ray tube will be intermittent.

SUGGESTED METHOD OF MEASURING QUALITY OF X-RADIATION.

The results obtained in the present Paper indicate at least this fact—namely, that the equivalent spark-gap as measured under conditions obtaining in X-ray practice is not a satisfactory measure, for purposes of standardisation, of the quality of the general radiation emitted by an X-ray tube where variable conditions of excitation obtain. A complete analysis of the radiation by the X-ray spectrometer is ideal, but scarcely within the range of practical realisation outside a well-equipped physics laboratory.

The results obtained with the various machines under conditions of constancy of quality of "end-radiation" show that standardisation is possible. Seeing that

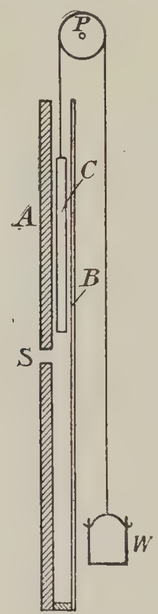

FIG. 9.

the same relative distribution of intensity can be obtained by a suitable adjustment of the conditions, whichever machine as used in our investigation is employed, the following standard method of measurement is suggested—viz., the percentage reduction of intensity by 1 cm. of aluminium. This reduction of intensity is unique for a definite intensity distribution, and corresponds to a definite quality of "end-radiation."

E. A. Owen* and P. K. Bowes have shown that the pastille method of measuring intensity agrees with the ionisation method; consequently the ratio of the time required for a pastille dose with an aluminium filter of 1 cm., to that without the

* Journ. Röntgen Soc., July (1921).

filter would give a measure of the "hardness" of the radiation emitted by the tube. The procedure affords a method of measurement easily applied in practical radiology. For any given outfit the indications by this method could be calibrated against equivalent spark-gap.

In conclusion, we wish to thank the Governors and Principal of the Sir John Cass Technical Institute, Aldgate, for the facilities granted in the carrying out of this research; also to express our indebtedness to Dr. D. Owen for valuable suggestions during the preparation of the Paper.

DISCUSSION.

Dr. G. W. C. KAYE (communicated): The main feature of the authors' Paper is, perhaps, their deduction that the sphere gap does not provide a trustworthy measure of the peak voltage operating an X-ray tube, or alternatively, of the hardness of the "end radiation." The work of Peek and others in America on the sphere gap has been generally accepted by electrical engineers, and the belief is current that the sphere gap is in general capable of an accuracy of a few per cent., and that it is unaffected by either periodicity or steepness of wave front. It is true that the added factor of an X-ray tube was not present in Peek's experiments, but, nevertheless, the work of Dauvillier (to which the authors refer) seems to show that no very striking anomalies, at any rate up to 100 kv., attend the use of the sphere gap when used in parallel with an X-ray tube.

The authors in the present Paper use peak voltages up to 86 kv., and one is led to examine their results. Some ambiguity arises from their use of the term "end radiation." Rutherford, who I believe coined the term, meant it to refer to the X-ray of shortest wave-length present—that is, the quantum limit of the X-ray spectrum, the frequency of which is directly proportional to the maximum potential employed A glance at a typical spectral curve shows that the intensity of this shortest wave in a spectrum of rays is very small, and thus to filter out the rest of the radiation with any approximation to completeness, the initial radiation must be cut down to a very small fraction.

Now if in Figs. 3, 4 and 5 of the authors' Paper we produce back to the "y" axis the straight-line portion of the curve, we readily ascertain that their "end radiation" refers to what is left after only 70 or 80 per cent. of the initial radiation has been absorbed. Their values of the absorption coefficients (μ) are average figures for the residual 20 or 30 per cent. It is perhaps, therefore, not surprising that no simple relation is found between μ and the peak voltage as measured by the sphere gap.

From experience of similar absorption measurements (*see* Kaye, Proc. Roy. Soc., Series A, Vol. 93, p. 427, 1917), one is aware how slowly the slope of the log absorption curves changes with the greater thicknesses, and how tempting it is to run a straight line through the observational points. But, nevertheless, one is really only drawing a tangent, and if one continues the observations not to a residual intensity of the order of 1 per cent., but far beyond, say, 1 in 10,000, one sees that the absorption curve is not really straight, but slowly flattening out all the time. Rutherford's observations (Phil. Mag., Sept., 1915) show this clearly for voltages from 22 to 96 kilovolts.

The above refers to "general" X-rays, but the presence of characteristic radiation may have to be reckoned with, as the presence of an appreciable amount of it tends to produce a straight region in the log absorption curve. Now it so happens that the critical voltage for the K-radiation of tungsten is about 70 kv. and the optimum about 100 kv. It seems likely then that the residual 20 or 30 per cent. on which μ is based contains an admixture of K-radiation to an extent which increases with the voltage.

It appears then that the authors' μ refers to no definite radiation, but may be associated with a wave-length which is, so to speak, the centre of gravity of the spectral curve of the group of residual rays containing both general and characteristic rays. It is probable that this mean wave-length approximates to that of the peak or maximum intensity of the spectral curve. On the other hand, the sphere gap refers (or so we have grown to believe) to the quantum limit the wave-length of which bears no certain relation to the mean wave-length with which the authors are dealing.

There is evidence to show, and it seems to me to be very probable, that the spectral curves

of X-rays excited, *ceteris paribus*, by different types of potential generators may differ slightly if not appreciably in form. Such differences would be emphasised by filtering, and we therefore have an explanation why μ as determined by the authors is not the same for different machines.

The shape of spectral curves is altered by change of exciting voltage, and as their area is a measure of the intensity, it is not difficult by adjusting one or the other variable or both, to make differently excited spectral curve "fit" approximately and so have the same μ. As the authors' results show, the "fit" is exact enough to satisfy absorption measurements, which at best are not a very sensitive test.

For the above reasons I do not agree that the results of the authors throw discredit on the sphere gap as a measurer of peak voltage on an X-ray tube. It is true that the sphere gap requires precautions—for example, in the absence of a high resistance in series, it will, if the gap is left near the sparking value as described by the authors, usually measure the occasional surges which are of higher voltage than the normal.

I have only one comment to make on the X-ray photograph showing intermittent discharge with a Wimshurst machine. Similar results have been obtained by other workers with coil and transformer discharges, and it should be cleared up as to whether or not such photographs are produced by higher frequency currents superposed on the main potential curve. The existence of such currents is well known, and their frequency and indeed their existence are controllable by capacity, inductance or resistance changes.

The AUTHORS (in reply): Much of Dr. Kaye's criticism is directed against an alleged deduction which we do not make, viz., "that the sphere-gap does not provide a trustworthy measure of the peak voltage operating an X-ray tube." We do not claim this; on the contrary, we agree that there seems to be little doubt that with adequate precautions the sphere-gap is a reliable measure of peak potential. We do, however, conclude that the quality of the "end-radiation," viz., that left after transmission through 1 cm. of aluminium (which corresponds approximately to that used in medical radiology), is not satisfactorily measured by the equivalent spark-gap. There should be no ambiguity about the term "end-radiation," which we clearly define in the Paper. Reference to Rutherford's Paper mentioned by Dr. Kaye shows that he understood it to be the radiation which after filtration shows constancy of absorption coefficient in aluminium.

Since radiation corresponding to the "end-radiation" is that frequently employed in practice, and equivalent spark-gap is taken as a measure of its quality, it becomes important, if possible, to correlate the two. Our experimental results show that this cannot be done satisfactorily, at any rate, under conditions obtaining in practice. As Dr. Kaye points out, the intensity of the radiation of shortest wave-length (corresponding to peak potential) is vanishingly small. It therefore contributes to a negligible extent to the useful radiation, and unless there is some correlation between the average quality of the "end-radiation" and the shortest wave-length in the spectrum, this is an additional argument against the use of the equivalent spark-gap as a measure of the general quality of radiation employed in practice.

The presence of characteristic radiation, if appreciable, is a disturbing factor which, however, seeing that its wave-length is independent of the applied voltage, would give added weight to the conclusion that the quality of the residual or end-radiation bears no simple relationship to the equivalent spark-gap. Examination of the curves of Fig. 6 reveals a tendency for the coefficient of absorption of the end-radiation to become independent of applied voltage for the higher values. This is due no doubt partly to a greater proportion of the absorption being due to scattered radiation, but probably also to an increasing proportion of the radiation being characteristic K-radiation.

Dr. Kaye points out that the coefficient of absorption which we measure refers to no definite radiation. In his "Practical Applications of X-rays" (Chapman & Hall, 1923) he reproduces in Fig. 29 spectral curves by Hull showing the effect of filtering the radiation through 3 mm. of aluminium, from which it is seen that filtration narrows down considerably the range of wave-lengths transmitted, and that the point of maximum intensity is shifted towards the shorter wave-lengths. This narrowing down of the range will be considerably more pronounced with 1 cm. of *Al* and, as absorption experiments show, is sufficient to give rise to constancy of absorption coefficient within the limits of experimental accuracy. It is therefore sufficiently definite for the purpose in view. It is quite true, as Dr. Kaye suggests, that the straight lines give average results and that in reality the lines are not strictly straight. This is obvious from

the spectral curves, but it does not in our opinion modify the conclusions to be drawn from the absorption curves.

We fail to see how the results we have obtained admit of the explanation that different spectral curves can be made to fit approximately. We have selected the same value of μ for the different machines, i.e., the same average wave-length of end-radiation after filtering out from 80 to 95 per cent. of the radiation of longer wave-length. When this is done, as we have demonstrated in the Paper, there is a very close " fit " of the absorption curves for the whole of the initial radiation, which we think can only be obtained by a close similarity of spectral curves for the selected conditions. If, as Dr. Kaye proposes, differences in spectral curves are emphasised by filtering, there is all the more reason to conclude that the similar absorption curves obtained indicate similarity of spectral curves.

There appears to be no doubt from our results and from those of Dauvillier that spectral curves obtained with the different machines display a close similarity when the conditions are suitably adjusted. Since each instantaneous potential gives rise to a spectrum of radiation, it is quite conceivable that, within limits, differences in the original wave-form are relatively unimportant in the resulting X-ray spectrum.

There appears to be no advantage in adopting the procedure of producing the straight portion of the curve back to the log-intensity axis. This gives the intensity remaining after absorption expressed as a percentage, not of the intensity of the original heterogeneous beam, but of that radiation in the initial beam, which has the same coefficient of absorption as the " end-radiation." The residual intensity expressed as a percentage of the total initial intensity is obtainable from our experimental results direct.

With regard to Dr. Kaye's suggestion that the intermittent effect with the Wimshurst machine may be due to high-frequency currents superposed upon the main discharge, this possibility has not been overlooked. The low frequency of intermittence seems to rule out this explanation, but the question is being fully investigated by E. J. Evans.

PRACTICAL X-RAY MEASUREMENTS FOR MEDICAL PURPOSES.

BY

DR. MARTIN BERRY.

§ 1. SINCE the science of radiology as a whole has now become an integral portion of many other sciences and arts, and since advances in the science can only result from physical investigations, no single sphere in which its utility has been manifested can claim the whole attention of those whose duty it is to investigate the general phenomena.

We who employ rays in the diagnosis and treatment of diseased conditions are apt to consider this as their chief application, but we must not overlook the other claims that are made on the attention of the physicist. To physics we owe the discovery of the rays, and to physics we have looked, and not in vain, for further advances. At the same time it behoves every medical man who practises radiology to understand not only the biological effects of radiations, but also the physical conditions under which they are produced, and the various devices by which the characteristics of the rays can be altered.

Medicine has particular limitations of its own to impose which may possibly be lost sight of during general physical investigations. When dealing with inanimate objects it is immaterial whether an exposure lasts three hours, three days or three weeks, but this is not so in the case of patients. An even more important limitation is the possibility, or rather probability, in inexpert hands of causing active damage. Whilst it is true that journalistic enterprise has resulted in awakening needless alarm in the minds of the public, yet we must remember that the margin between inefficient and excessive dosage is narrow, and it is our bounden duty to make this margin as wide as we possibly can. This has been the purpose of the various measurements I have made, some of which are referred to in the present Paper.

One of the chief dangers which confronts us, and which imposes a limit on the dosage we can apply, is that of inflicting irreparable damage on the skin. In a very large proportion of cases we are dealing with lesions situated deeply in the human economy, which lesions are known to require a certain dosage for their destruction. To fall far short of this dosage may result in actual stimulation of the growth, so that we are left to steer between the Scylla of under-dosage and the Charybdis of over-dosage.

The first and most important consideration for us is the depth dose—that is, the proportion of radiation received by a growth in the interior of the body as compared with that received by the skin and tissues covering it. The first and most obvious device to increase the depth dose is the method of cross-fire, by which the lesion is attacked through several ports of entry ; but this method is not always available.

When we speak of practical measurements for medical purposes the subject really divides itself into measurements of the rays which are actually applied to the patient, so that we know what dose has been given, and measurements of the changes in the quality and quantity of radiation resulting from adjustments of the apparatus. It is chiefly the latter part with which I am dealing in an attempt to

show how a medical man who has to work with a particular set of apparatus may get the best out of it.

§ 2. The apparatus which was used for all the experiments is a twin coil working in conjunction with a mercury interrupter of the centrifugal jet type. Various makes of tubes have been used, all of them of the self-hardening, boiling-water variety.

The adjustments and variations possible on such apparatus are the amount of self-induction, the primary condenser capacity, the speed of the interrupter, and the duration of contact in the interrupter for each individual impulse ; of these, the interrupter speed is the most easily controlled and will be dealt with first. That considerable variations in the penetrating power of the radiation may result from simple changes of interrupter speed is shown by Table I., which is a single example of a large series giving similar results.

TABLE I.—*Variation of Speed of Interruption.*

Tube P. Filter 0·5 mm. zinc. Field 6×8 cm. Measurements on iontoquantimeter. Figures are times of discharge in seconds. Focus to centre of ionisation chamber 37 cm. Water tank 5 cm. thick behind ionisation chamber in all tests. Penetration taken through 10 cm. of water. Readings taken alternately without switching tube off. Boiling water tube.

					Mean.
3,080 interruptions per minute.					
Through 10 cm. water	25·4	24·2	24·4	24·4	24·6 sec.
Without front tank	7·8	8·0	8·8	8·0	8·2 ,,
2,640 interruptions per minute.					
Through 10 cm. water	23·2	22·8	23·0	23·6	23·2 sec.
Without front tank	8·6	9·0	7·8	8·4	8·5 ,,

Result.—12·8 per cent. penetration at 3,080 interruptions per minute and 16·6 per cent. penetration at 2,640 interruptions per minute.

Same tube and general arrangement as above.

Comparison of Penetration by Kienbock Strips.

Results.—15 per cent. penetration at 2,640 interruptions per minute.
17 per cent. penetration at 2,320 interruptions per minute.

The penetrations mentioned in these two tests are those which relate to the dose received by a lesion lying 10 cm. under the skin surface as compared with that received by the skin itself. The tube was in rather too soft a condition for deep treatment of malignant conditions.

If the secondary current pass through an oscilloscope tube which is viewed in a rotating mirror, or is itself revolved, as in the ondoscope demonstrated by Dr. Hopwood, it will be seen that the phenomena are those of intermittent discharges through the tube with much longer intervening periods when no discharge is taking place, each wave of current representing a single interruption. In a gas X-ray tube these intervals are important, not only since they allow the heat generated at the focal spot to be distributed through the mass of the target, but even more since it is in these intervals that the air space between the cathode and target becomes de-ionised, and thus allows the rise of voltage on the tube terminals which gives to

the electrons the velocity necessary to produce hard radiation. If we knew all the factors we should be able to say from the appearance of the oscilloscope discharge whether the resting period was too long, too short or just correct. But we can obtain the necessary information, without all these factors, by examining the radiation produced. Table I. shows such an examination at different speeds of interruption, carried out by readings on an iontoquantimeter and checked by another experiment with Kienbock strips. By taking a series of such measurements it is possible to obtain the optimum speed for each given set of working conditions. In the experiments in question readings were taken of the intensity of radiation received by an ionisation chamber, both with and without the interposition of 10 cm. of water between the source of rays and the chamber, the rays having already passed through 0·5 mm. zinc before reaching the water tank. In the experiments of Table I. the depth of dosage is given under the conditions laid down by the Erlangen technique.

Another point in connection with the interrupter which should be capable of variation is the duration of contact, and it is to be regretted that so many interrupters are constructed in which this adjustment is not possible. For any given set of working conditions there is one length of contact which is correct; a shorter time of contact than this gives insufficient saturation, and a longer one passes an unnecessary amount of current through the primary, in addition to encroaching on the de-ionisation interval of the tube. My experiments on this point are not sufficiently advanced for publication.

With regard to varying self-induction, as a rule this is only possible in very few steps, and on my own apparatus one degree is so obviously better than the others that it is the only one I have used.

Turning now to variations of the condenser. Much work has been done on this subject, but some of it is not applicable to apparatus already purchased, though it may be of great value to the manufacturer of such apparatus. In particular, the work of Taylor Jones was carried out under conditions different from those which obtain in a modern radio-therapeutic department. Seitz and Wintz have published the results of tests with their own apparatus, showing a very marked optimum capacity. This optimum depends on so many factors that it cannot be transferred from one apparatus to another; the results of tests on my own apparatus are shown in Table II. In this series of measurements the only factor altered was the condenser capacity, and the influence of this variation is exceedingly marked. The figures show a steady rise in the primary current, whilst the secondary current only varies slightly, the extra amount of energy intake being expended largely in the form of increased voltage.

The lower part of the table shows an optimum at 3·97 microfarads, which is approximately the same as that obtained by various other series of tests. The columns headed "Air" and "Water" represent the time taken in seconds for the discharge of the iontoquantimeter, respectively without and with the interposition of 10 cm. of water in the path of the rays between the filter and the ionisation chamber. The field of irradiation in these experiments was larger than that used in Table I., and the distance from focus to ionisation chamber was greater, hence the percentage penetration is greater. These experiments were carried out more nearly under my practical working conditions than those of Table I. As a general rule, I prefer a smaller number of fields each of larger area and a comparatively long focus-skin distance to the technique of a larger number of smaller fields with a shorter distance.

TABLE II.—*Variation of Primary Condenser.*

Experimental Details:—Boiling water tube. Measured on iontoquantimeter. Focus to ionisation chamber 46 cm. Diaphragm 6×8 cm. midway. Water tank 20 cm. square and 10 cm. deep. Wax block behind ionisation chamber. Filter 0·5 mm. zinc. Spark gap 40 cm. between points. Tube rheostat 12. Motor rheostat 7. Auxiliary rheostat 7·5.

Micro-farad.	Penetro-meter.	Amps.	M.A.	Time in secs.	
				Air.	Water.
2·0	75	5·5	1·9	12·8	30·8
2·93	80	5·5	1·8	12·4	31·6
3·06	81	6·5	1·9	13·0	32·6
3·2	80	6·5	1·9	12·8	31·0
3·97	88	8·5	1·9	10·8	22·0
4·26	91	9·0	1·9	11·0	25·0
2·0	76	5·5	1·9	14·0	33·0
2·93	81	6·0	1·9	12·0	30·0
3·06	83	6·5	1·8	12·2	28·2
3·2	85	6·5	1·9	12·0	28·6
3·97	94	9·0	2·0	10·0	23·0
4·26	95	9·0	1·9	10·2	22·6
2·0	74	5·0	2·0	15·0	35·0
2·93	82	6·0	1·9	12·4	27·2
3·06	83	6·5	1·9	10·8	27·4
3·2	85	7·0	1·8	11·8	28·6
3·97	94	9·0	1·9	11·6	22·6
4·26	94	9·0	1·9	10·4	24·6

Above figures arranged under condenser capacity.

Capacity, microfarad	2·0	2·93	3·06	3·2	3·97	4·26
No water ...	12·8 14·0 15·0	12·4 12·0 12·4	13·0 12·2 10·8	12·8 12·0 11·8	10·8 10·0 11·6	11·0 10·2 10·4
Mean	13·9	12·3	12·0	12·2	10·8	10·5
10 cm. water	30·8 33·0 35·0	31·6 30·0 27·2	32·6 28·2 27·4	31·0 28·6 28·6	22·0 23·0 22·6	25·0 22·6 24·6
Mean	32·9	29·6	29·4	29·4	22·5	24·1
Per cent. through water	42·3	41·6	40·9	41·5	48·0	43·6

In addition to the figures in Table II. it may be stated that with a condenser of only 2 microfarads the working of the tube was most irregular and the conditions not suitable for treatment of a patient. The alternate spark-gap (between blunt points) was set at 40 cm., and as the condenser capacity was raised sparks bridged this gap with increasing frequency until, at the two highest capacities used, they were almost continuous. I did not wish to alter the gap, but had this been done the figures for the larger capacities would have shown still greater superiority over the other figures. The readings were taken in the order given in the upper part of the table in order to eliminate as far as possible any error due to variation of tube condition.

§ 3. Let us assume now that we have produced a quality of radiation which we regard as suitable for application to a patient, and turn to some consideration regarding its application. Let us also remember that our primary object is to make the depth dose as large as possible compared with the skin dose. Though consideration of the patient's feelings and comfort causes us to shorten the time of dosage as much as possible, yet we must not sacrifice efficiency for this purpose.

One method of increasing the depth dose is to cover the surface of the body with a layer of some material which has approximately the same coefficient of absorption as the tissues. Rays are absorbed according to an exponential law, and therefore the actual amount of energy absorbed in the superficial layers is greater than that in the deeper layers. Add to this the fact that the superficial layers lie nearest to the source of origin of the radiation, and it is obvious that the amount of radiation affecting them is much greater than that affecting a corresponding layer in the depths. Since there is very good ground for believing that the biological effect is proportional to the amount of energy absorbed, we are in the position that the greatest absorption and biological effect occurs in the skin ; and this limits the depth dose which we can apply. It is with the purpose of reducing this disparity as far as possible that the body surface may be covered with a layer of some centimetres of material to take up this strong absorption.

In most of the experiments designed to examine the distribution of ray intensity water has been used as an absorbing and scattering material, since it behaves in this respect similarly to body tissues. It is, however, rather inconvenient to cover the body surface with a layer of water, and other materials have been used. Paraffin wax has been employed extensively for this purpose. From Table III. it will be seen that paraffin wax is wholly unsuitable, and that its use for this purpose would give entirely fallacious ideas about actual dosage. Various compounds were tried as substitutes for wax, but the result of tests of the latest composition is not entirely satisfactory for two reasons. Firstly, because it still allows a rather greater percentage of radiation to pass through than water does ; and, secondly, because it is not sufficiently plastic to be moulded easily to the contours of the patient. A formula for a mixture which would satisfy these two conditions would be a boon. It is fairly easy to evolve a formula to satisfy either condition, but it is essential that both should be complied with. If we are building up the surface of the body with a mass which we intend to consider as forming a homogeneous whole with the body for the purposes of calculation and measurement, it really must adapt itself to the surface without leaving air spaces ; some portions of the body present great difficulties in this respect. At the same time, the material should be capable of retaining its shape without the necessity of enclosing it in bags or other containers. Possibly dough, which is the next material it is proposed to try, may prove suitable. In Germany a pulp of cellulose is used, but this does not retain its shape satisfactorily.

§ 4. One final point on which comment should be made is the importance of back-scattered radiation. Table IV. gives in its upper part the results of some measurements made with a water phantom, and, below, a trial with Kienbock strips on a patient during an actual treatment. The importance of back-scattered radiation in practical therapy becomes most evident in cases where it may be diminished in the depths, such, for example, as in the treatment of a case of uterine cancer, where a gas-filled rectum lies behind the uterus. The skin always receives radiation scattered back from the subcutaneous tissues, and the amount of such radiation is

well shown in the curves published by Prof. Dessauer, of Frankfort, to whom I am indebted for much useful information and assistance. This effect of back-scattering calls for caution when radiating two skin fields close to each other.

TABLE III.—*Comparison of Penetrations through Water, Paraffin Wax and Compo Wax.*

Tube M. boiling water. Filter 0·5 mm. zinc. Focus to ionisation chamber 33 cm. Diaphragm 6 × 8 cm. at 23 cm. from focus. Alternate spark gap 40 cm. Readings taken alternately.

Times of discharge of iontoquantimeter in seconds.					Mean.
10 cm. water in front and 5 cm. behind ...	22·4	22·6	22·2	22·0	22·3 sec.
10 cm. P. wax in front and 5 cm. behind	15·4	15·6	17·0	17·2	16·3 „
No front tank, wax behind	7·0	7·8	7·8	8·0	7·6 „

Result.—34·1 per cent. transmitted through water and 46·6 per cent. through paraffin wax.

Experiment to Compare Paraffin Wax and Compo Wax with Water.

Tube P. boiling water. Other experimental arrangements as above. Dimensions of all tanks and wax blocks 20 cm. square. Front tanks and blocks 10 cm. thick, back tanks and blocks 5 cm. thick. Times of discharge of iontoquantimeter in seconds. In all the experiments the back tank was water.

				Mean.
10 cm. of water in front	23·9	23·3	24·0	23·7 sec.
10 cm. of compo in front	22·6	22·5	23·0	22·7 „
10 cm. of P. wax in front	19·4	19·6	18·8	19·3 „
No block in front	7·6	7·2	7·2	7·3 „

Result.—Radiation transmitted through 10 cm. water, 30·6 per cent.
Radiation transmitted through 10 cm. compo, 32·1 per cent.
Radiation transmitted through 10 cm. P. wax, 38·0 per cent.

TABLE IV.—*Importance of Back-Scattered Radiation.*

Tube P. boiling water. Filter 0·5 mm. zinc. Focus to centre of ionisation chamber 37 cm. 2,640 interruptions per minute. 6·5 amps. in primary, 2·2 M.A. in secondary. Front water tank 20 cm. square and 10 cm. thick. Tank behind ionisation chamber 20 cm. square and 5 cm. thick.

Times of discharge of iontoquantimeter in seconds.					Mean.
Tanks front and back	19·4	20·4	20·0	21·0	20·2 sec.
Tank in front only	25·8	26·4	25·4	25·8	25·8 „
Tank at back only	6·6	7·8	7·0	7·4	7·2 „
No tanks	10·0	9·2	10·2	10·2	9·9 „

Result.—The intensity in the ionisation chamber becomes increased by 27 per cent. if the rays have passed through 10 cm. of water, and by 37 per cent. if they have only passed through air between the filter and the ionisation chamber, these percentages being the amounts added by the radiation scattered back from the tank behind the ionisation chamber.

Experiment to show amount of back-scattered radiation under actual conditions of treatment. A field 6 × 8 cm. was being treated, and a Kienbock strip was placed with the sensitive surface downwards on the patient's skin 4 cm. distant from the edge of the field. Its back was protected by thick lead, so that the only radiation it received was that back-scattered in the patient. Whilst the field received a dose of 26 X, the strip placed outside it showed 1·75 X.

A similar experiment under the same conditions showed 6·5 X on the field and 0·5 X on the strip.

The figures of Table IV. speak for themselves. They have been selected from a large number of similar experiments. The trial by Kienbock strips on the skin of the patient shows that this effect actually does occur in practical work, and is not merely a theoretical consideration.

In conclusion, I should like to say that only the fringe of a very large subject has been touched, and that there are many other devices which may be used to help us towards our goal—the cure of disease.

DISCUSSION.

Mr. F. HARRISON GLEW, referring to the problem of protecting the skin of the patient, stated that long experience had shown him that ordinary table jelly satisfies all requirements in this connection. Its absorptive qualities are approximately the same as those of water, and it can either be moulded to any required shape or applied in the form of overlapping wedges for convenience in adjusting the thickness of the absorbing layer.

X-RAY PROTECTIVE MATERIALS.

BY

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ABSTRACT.

The protective values expressed in terms of the equivalent thickness of lead have been measured for a variety of materials. Numerically, 1 mm. of the material in question is equivalent to the following thicknesses of sheet lead in millimetres :—

Lead glass	0·12 to 0·20
Lead rubber	0·25 to 0·45
Bricks and concrete	About 0·01
Woods	0·001 or less
Baryta plaster	0·05 to 0·13
Steel	0·15

The above figures relate to tungsten X-rays generated by 100,000 volts.

INTRODUCTORY.

THE steady addition to the already lengthy list of casualties to hospital and other X-ray workers led to the formation nearly two years ago of an X-ray and Radium Protection Committee (under the chairmanship of Sir Humphry Rolleston), which drew up a series of recommendations for the better protection and general improvement of the working conditions of the X-ray operator. These recommendations have resulted in a large number of X-ray protective materials being submitted for test to the National Physical Laboratory, which from the outset agreed to work in co-operation with the Committee, and has inspected the X-ray departments of many hospitals from the point of view of the Committee's recommendations.

It is well known that the absorption of an atom is greatest for those X-rays which have wave-lengths slightly shorter than one or other of its characteristic radiations, and partly with this in mind it was thought that it would be of value to ascertain the protective efficiencies of the various materials which are commercially available for the purpose of affording protection to the radiologist. Among these are sheet lead, lead impregnated rubber, lead glass, and various wall compositions such as barium-sulphate plasters, &c. The choice of one or other is normally dictated by considerations such as dielectric strength, portability, electrical and thermal conductivity, and not least by price.

Protection may be afforded in a variety of ways in practice. For example, by mounting the tube in a surrounding tube box suitably designed to permit the freedom of movement desired, or where this is impracticable the operator and his controls are situated behind a screen or wall which is constructed to give the necessary protection. Less frequently and conveniently the operator is "armoured" and wears protective aprons, gloves, face mask or goggles.

To the inexperienced the practice of speaking of percentage absorption may be misleading and calculated to give a wrong impression of the value of a protective material. It is not always realised how rapid the rate of absorption is with thin layers, and how slow with thicker layers. For example, in the case of tungsten X-rays generated at 120,000 volts, a sheet of lead only 0·1 mm. thick absorbs as

much as 80 per cent. of the radiation, whereas a sheet 2 mm. thick only increases this figure to 99·4 per cent.

For simplicity, therefore, the Protection Committee recommended that the protection afforded by a material should always be referred to in terms of the equivalent thickness of lead. This use of lead as a standard of reference, while not wholly free from objection, is very convenient for the approximate accuracy which suffices in practice, especially in dealing with composite or laminated materials as the lead values of the several layers can be regarded as additive. The Committee laid down certain thicknesses of lead which it regarded as the minima which should be employed under specified conditions; and, in view of the very unsatisfactory conditions which prevail in the majority of X-ray installations in this country, we have been led to put on record some of our measurements in this connection.

Apparatus.

The method of test adopted by the Laboratory is the very simple one of measuring by an ionisation method the absorption of a beam of X-rays by a material of given thickness, and then ascertaining the thickness of lead sheet which produces

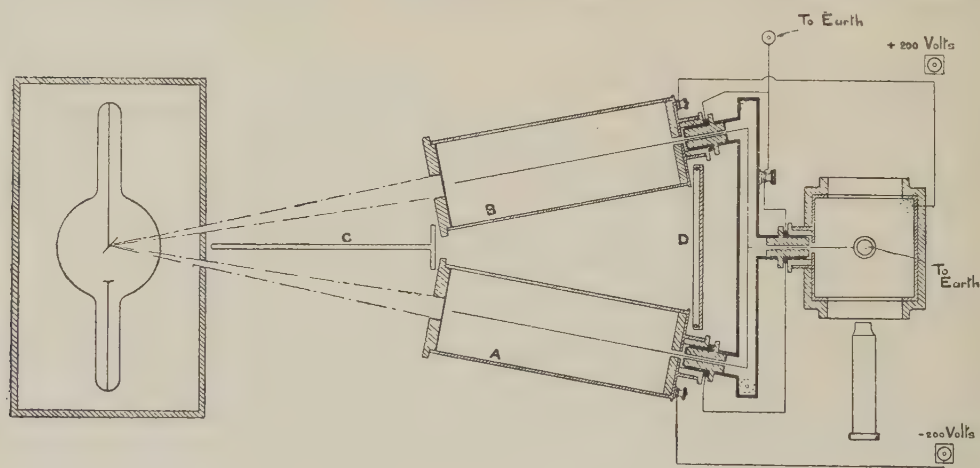

Fig. 1.

the same degree of absorption. A Coolidge tube with a tungsten target is usually employed for the purpose and, to avoid any possible anomaly arising from selective absorption, comparisons are conducted with at least two different exciting voltages. The size of the pencil of rays utilised is dictated by the absorptive qualities of the specimen to be measured. An obvious convenience is the provision of a series of lead sheets graded in progressive order of thickness which can be rapidly piled at will.

Fig. 1 shows in plan the details of an apparatus employing a balance method, which proves a useful alternative to the direct method referred to above. The diagram is self-explanatory, but one or two points may be mentioned. The two ionisation chambers *A* and *B* are exactly alike and placed as symmetrically as possible with respect to the target of the X-ray bulb. The near ends are closed

with aluminium sheet 0 5 mm. thick. The various insulating plugs are of ebonite with sulphur ring insertions and earthed guard rings. The sides of the electroscope are of lead 3 mm. thick. The gold-leaf system is initially earthed. The outer case of the electroscope is raised to 200 volts, whilst the outer cases of the two ionisation chambers are raised to +200 and − 200 volts respectively. Suitably disposed lead screens *C* and *D* prevent anomalies rising out of scattered or stray radiation.

The whole system is mounted on a wooden stand provided with levelling screens and means of lateral adjustment, so that the position of exact balance of ionisation between the two chambers can readily be found. When this has been secured, the test sample is placed in front of one of the ionisation chambers, and the thickness of lead in front of the other chamber rapidly altered until balance once again results.

The above two methods serve in general, but there are certain protective articles, the shape of which makes it difficult to test the protection afforded in all directions. To cope with these exceptional cases, a third apparatus has been constructed consisting of a small exploring ionisation chamber connected by a flexible conductor to a gold leaf electroscope.

Results.

The table given on the following page contains the " lead equivalents " for a variety of materials, *i.e.*, the thickness of lead equivalent in absorbing power to unit thickness of the material. The results are mostly for X-rays generated by 100,000 volts, but the values hold over a considerable range of some 20,000 or 30,000 volts on either side of this figure. The values are ordinarily diminished by from 5 to 10 per cent., when the voltage is 50,000. In the case of those materials which have feebly absorptive properties it was found convenient to compare them with lead through the intermediary of aluminium.

Provision is now being made for the measurement of lead equivalents at voltages ranging up to 200,000. It is intended also to extend the investigation to include gamma rays from radium.

Walls and Screens.

We have included a number of samples of building and other materials, as a knowledge of the various protective figures is not without value when buildings intended for radiological purposes are being erected. It will be remarked that the lead values of bricks and concrete are mostly of the order of 0·01. Thus, the lead equivalent of a 300 mm. (12 inch) solid concrete floor is about 3 mm. ; rather more for ferroconcrete. The majority of the woods have lead values of 0·001 or less.

With reference to iron, it will be noticed that its lead value is 0·15, and thus 20 mm. (about ¾ inch) of steel plate would be required to give protection equal to 3 mm. of lead, the figure recommended by the Protection Committee for exciting voltages over 100,000. The densities of steel and lead being about 7·8 and 11·4, the steel sheet would be four times as heavy as the lead. It so happens that this ratio is roughly that of the present cost by weight of lead and steel sheet,* so that

* About 40s. per cwt. for lead ; 10s. per cwt. for steel.

there is nothing in it on the score of cost. It may be noted, however, that lead would increase its protective ratio somewhat at deep therapy voltages. An objection to iron is its rusting tendencies.

Material.	Density.	Lead Equivalent.
Lead Rubber—		
(60 different samples)	3·7 to 6·5	0·25 to 0·45
Lead Glass—		
(40 different samples)	3·2 to 4·1	0·12 to 0·20
Metals—		
Aluminium	2·7	0·011
Brass	8·4	0·25
Steel	7·3	0·15
Miscellaneous—		
Water	1	0·004
50% red lead, 50% litharge	—	0·3
Ordinary rubber	1·2 to 1·7	0·02 to 0·05
Concrete—		
4 stone chippings, 2 washed sand, 1 cement	2·1	0·012
4 clinker, 1 cement	1·5	0·010
4 granite, 1 cement	2·1	0·013
Roman mortar	1·5	0·009
20 chalk, 1 cement	1·6	0·011
6 sand, 1 lime	1·8	0·009
Coke breeze	1·0	0·004
Bricks—		
Fletton brick (red)	1·6	0·010
Stock brick (yellow)	1·4	0·008
Diatomaceous brick	0·6	0·003
Protective Wall Plasters—		
(1) 55% Native Ba Co_3, 45% Ca So_4 ...	2·0	0·031
(2) 33% Ba So_4, 33% sand, 33% cement	1·5	0·048
(3) 33% coarse Ba So_4, 33% fine Ba So_4, 33% cement*	2·3	0·12
Woods—		
Ash	0·73	0·0013
Balsa	0·096	0·0001
Bass	0·48	0·0005
Fir	0·52	0·0008
Mahogany...	0·49 to 0·68	0·0006 to 0·0011
Oak	0·65	0·0008
White Pine	0·47	0·0006
Pitch Pine	0·53 to 0·56	0·0008
Spruce	0·41 to 0·43	0·0004 to 0·0006
Teak	0·58 to 0·76	0·0006 to 0·0011
Walnut	0·64	0·0008

* Mixture suggested by Mr. P. J. Neate.

Incidentally, sheet lead is commercially described and sold by its weight per superficial foot, " 2 lb. lead " referring to sheet lead weighing 2 lb. per sq. foot. In this connection the following table may be useful :—

Weight.	*Thickness.*	*Weight.*	*Thickness.*
2 lb. lead	0·8 mm.	7 lb. lead	3·05 mm.
3 ,,	1·25 ,,	8 ,,	3·5 ,,
4 ,,	1·7 ,,	9 ,,	3·95 ,,
5 ,,	2·15 ,,	10 ,,	4·3 ,,
6 ,,	2·6 ,,	11 ,,	4·75 ,,
		12 ,,	5·2 ,,

There is some tendency at the present time to employ baryta and other plasters in lieu of lead. We give the lead equivalents of three of these plasters. It may be remarked, to take the case of mixture No. 2, that 60 mm. (nearly 2½ inches) thickness will be required to give the protection of 3 mm. of lead, and that the weight of the plaster is nearly three times that of the lead. These figures would be more favourable for plaster No. 3. We have no knowledge of the costs of these plasters as compared with lead, nor of the cost of the labour involved in erection.

Certain plasters have been devised containing iron turnings. They possess no special merit as regards absorption, and the tendency to rust is a disadvantage.

Tube Boxes.

Protective tube boxes, if constructed of lead, have to be of dimensions sufficiently generous to prevent sparking between the bulb and the box. If, however, the tube box is required to be in close proximity to the bulb, the former commonly takes the form of a lead glass bowl, or, alternatively, a wooden box with several layers of lead-rubber lining or wrapping. The open glass bowl is open to grave criticism : it is constructed of lead glass, usually affording, as our measurements show, a total protection of from 0·5 to 0·7 mm. lead ; but in many directions, owing to its design, it affords no protection whatever. In our experience, where this type of shield is alone employed, it is often possible to take a radiograph of the hand in any part of a room where a tube is working. The bowl should be provided with some kind of cover and the material increased in effectiveness.

The type of double hemispherical shield supplied for radiator Coolidge tubes is much better, in that it completely encloses the tube. The different shields (whether tinted blue or yellow) which we have tested have a lead equivalent of about 0·2, the total protection provided ranging between 1·2 and 1·5 mm. lead. The Protection Committee recommends not less than 2 mm. for exciting voltages below 100,000. We refer again to the question of lead glass in connection with protective windows, etc.

Different makes of lead rubber differ in protective value by 100 per cent., and the importance of this fact should be stressed. Care should be taken that the lead rubber is not cut away locally when the box is being constructed.

The choice of lead rubber or lead glass in preference to lead sheet is usually dictated by the fact that the former are electrical insulators, at any rate to a limited extent. The resistivity of lead rubber is usually of the order of several thousand megohm centimetres. The insulating value may be greatly improved by including

a layer of micanite, ordinary rubber or other suitable insulator among the layers of lead rubber.

Measurements of the dielectric strength have been made in the Electrical Department of the Laboratory on a considerable number of samples. Two circular electrodes 1½ in. in diameter with rounded edges were placed in contact with opposite sides of the material, an alternating potential of approximately sine wave form being applied and steadily increased from zero until the material punctured. For good specimens of lead rubber the breakdown voltage was about 5,000 to 12,000 R.M.S. volts per millimetre thickness. In other cases the values were a good deal less, and on occasion the material acted as a conductor. For lead glass the values ranged from about 5,000 to 9,000 R.M.S. volts per millimetre.

One other point may be referred to. In a prolonged run, especially with a Coolidge tube, a great deal of heat has to be got rid of, and it is usually advisable to provide for ventilation of the tube box; in that event the openings should be properly safeguarded from a protection standpoint. A knowledge of the thermal conductivity of the several protective materials may be useful in this connection. Measurements at the Laboratory show that the values of the thermal conductivity at room temperature are as follows in c.g.s. Centigrade units :—

Woods (various)	About 0·0003
Ordinary rubber	,, 0·0008 to 0·0011*
Lead rubber	,, 0·0003 to 0·0007
Lead glass	,, 0·002
Lead	,, 0·08

If considerations of weight are of first importance, then lead sheet is almost always the lightest among the protective materials commonly employed for tube boxes. For example, the protective values of lead rubber range between about 0·25 and 0·55, and the densities between about 3·7 and 6·5. On the average, lead rubber is about 10 per cent. heavier than sheet lead, affording the same protection, though it may be as much as 25 per cent. and as little as 5 per cent.

Similarly with lead glass the protective values commonly lie between 0·12 and 0·20, and the densities between 3·2 and 4·1. On the average, lead glass is about twice as heavy as sheet lead, affording the same protection, the figures ranging from about 1·75 to 2·5.

These results (as with those for the screen materials) are, of course, predictable, as it is known that a heavy atom is ordinarily much more absorbent than a light. For the same reason in the case of two composite materials, each containing a mixture of atoms and having the same density, the one containing a higher proportion of heavy atoms will usually have a higher absorption factor. With lead rubber the lack of proportionality between density and lead value is sometimes pronounced, and of two samples the one with the lower density may have the higher lead equivalent.

Diaphragms of the iris type are often fitted to tube boxes. The leaves are usually much too transparent. They should provide protection equal to not less than 3 mm. of lead, and the simpler rectangular diaphragm with two motions is a more practical job.

* Depending on the mineral content.

Protective Glass Screens or Windows.

As already mentioned, the lead values of lead glass range between about 0·12 and 0·20 per mm. But glass with the highest values, while perfectly mouldable into protective bowls and the like, is inadmissible for fluorescent screens and windows on account of the impossibility of producing it in flat sheets free from streakiness and colour. Such sheets are rarely more than 4 to 6 mm. thick, and to get the minimum protection recommended by the Protection Committee for fluorescent screens or windows it may be necessary to pile several sheets, a proceeding which is impracticable, as it becomes impossible to see through them.

One has to turn to glass of lower lead content, and this can be obtained in sheets, perfectly flat, of great clarity and almost colourless. The lead value is about 0·12 per mm., but as sheets up to 18 mm. thick can be obtained, the requisite protection is readily afforded, though at the cost of greater weight.

Miscellaneous Materials.

Among these are included aprons, gloves, face masks and goggles, of which the minimum protective value recommended by the Protection Committee is ½ mm. lead. The Committee were deterred from recommending a higher figure by considerations of weight and convenience. For obvious reasons lead rubber and lead glass are almost solely utilised in the manufacture of the above articles. The linings of chamois leather or stockingette often employed, while having no appreciable lead value for the primary rays, are doubtless useful in absorbing the softer characteristic rays of lead.

DISCUSSION.

Dr. H. B. Keene (comunicated) : I should like to support very strongly the views expressed by Dr. Kaye regarding the inadequacy of X-ray protection in many existing equipments. I have had similar experiences when inspecting hospital and clinic installations in other parts of the country. One or two examples may serve to show how unsatisfactory the conditions may be.

I have seen protective goggles in use in which one window was of lead and the other of soda glass. I have seen a modern Coolidge outfit for radioscopy in which the protection has been so totally inadequate that a fluorescent screen held in the hand in practically any part of the room showed an excellent picture of the bones of the forearm.

I recall a vertical screening stand of modern manufacture which, although beautiful to look upon, leaked X-rays in such a direction that they fell full on the operator at his control table and over the full length of his body. This condition had continued for some eighteen months. A similar leakage below the vertical lead rubber screen provided a bath of scattered radiation for the legs and feet of the doctor who sat and examined the patients.

Recently an outfit has come to my notice in which the entire tube protection consists of a portion of a hemisphere of lead rubber sheet 0·8 mm. thick.

It is very evident from what Dr. Kaye has said that such undesirable conditions are not uncommon. The X-Ray and Radium Protection Committee and their collaborators at the National Physical Laboratory are doing an excellent and very necessary work. But the rules which they have drawn up and the valuable protective data which Dr. Kaye and Dr. Owen have made available need to be brought very directly—perhaps by a succession of further printed pamphlets—to the notice of the *authorities* responsible for the various X-ray equipments throughout the country, as well as to the notice of the operators themselves.

There seems to me to be a very strong case for the compulsory inspection of existing installations and of those which are being daily produced by the makers, if only on the grounds that those who operate them exercise a "dangerous occupation."

GENERAL DISCUSSION.

In addition to the discussion already recorded in connection with the various Papers, the following contributions were made :—

Major C. E. S. PHILLIPS said that radio-therapeutic methods seemed to be acquiring a nutritive as well as a curative value, since Dr. Berry proposed to coat the patient with dough and Mr. Glew with jelly. As a member of the Röntgen Society, he desired to express his sense of the value of the present meeting, which was the first joint meeting held by the two societies, and his hope that it would not be the last. It is important that physicists should know what are the chief practical difficulties of medical men in order that they may be able to concentrate attention on these, and it is equally important for medical men to become familiar with the latest methods devised by pure scientists.

Dr. G. B. BATTEN, speaking as one of the oldest medical members of the Röntgen Society, said that a meeting like the present must be valuable to the future practice of radiologists. Every advance in knowledge can sooner or later be turned to advantage for the well-being of humanity. Even the thermionic valve, which was invented for a purely commercial purpose, has recently been used in electro-medical treatment for measuring the current passing through the tissues of a patient. It is important that investigators working in separate departments of science should cultivate a readiness both to get and to give knowledge.

Dr. N. S. FINZI said that he considered Major Phillips had hit the nail on the head when he mentioned the difficulties surrounding radiologists. Most of the work brought before them that evening was concerned with voltages much lower than those which radiologists used in modern work. The communications dealt with pressures of about 100 K.V. and 120 K.V., whereas for modern treatment pressures of 200 K.V. to 250 K.V. were employed ; it was likely that they would soon employ higher pressures still. It seemed therefore desirable that British physicists should give more attention to this more difficult part of the spectrum and the difficulties and dangers which arose from its use. He used a Sabouraud pastille for measurement and found it quite satisfactory if one remembered that the dose was not the same as with rays corresponding to rays of lower pressures. With rays produced by pressures of 220 K.V. to 260 K.V. and using filters of 0·8 mm. of copper and 3 mm. of aluminium the dose was three times the Sabouraud B. Tint.

He had recently been on the Continent and seen some of the newer work in France and Germany. In Germany there is a new instrument made by Siemens and Halske in which the ionisation current through a small ionisation chamber, made, he believed, of horn, was measured by means of a galvanometer after amplification by a triode valve and the apparatus used was so arranged that a continuous reading was obtained without the necessity of intermittent charging and discharging of an electrometer, valuable time being thus saved. Wintz and Rump have shown by means of an arrangement of tanks containing water and air that the amount of rays received at a certain point varies considerably according to where the air space is placed, the total proportions of water and air remaining the same ; the least radiation was received when the air space was nearest to the point being measured. Consequently the effect of gas in the intestines and similar organs is of the greatest importance. An attempt was made to deal with this by increasing the pressure of the applicator on the patient's abdomen. They were also getting greater accuracy by localising the exact position of their beam of rays by means of a lead pellet used under the guidance of a fluorescent screen. In France he saw a new apparatus for producing high-tension current, comprising two transformers connected through four kenotron rectifiers with four condensers, this instrument producing continuous current up to 250 K.V. He only saw it working up to 150 K.V., as they had not a tube which would stand up to a higher voltage. All measurements of voltage, current, the output of rays and everything else were carried out on a switchboard under the control of the operator. The X-ray output was measured directly by means of a current from a 500-volt dry battery passed through a very large ionisation chamber and then through a galvanometer.

Mr. F. E. SMITH referred to Prof. Russ's suggestion that an International Committee on Standards of Measurement in Radiology should be set up. The present situation with regard to the latter is seriously unsatisfactory, and if a lead is to be given, the Physical and Röntgen Societies would seem to be the appropriate bodies to take the initiative. He invited all who are interested in the matter to communicate with the Secretary of one or the other of the Societies.

Mr. M. A. CODD said that a committee of the kind referred to had been appointed in 1905. Perhaps Major Phillips could say whether it had done anything ? At present every medical practitioner has his own empirical standard of measurement, but some uniformity of practice is very desirable.

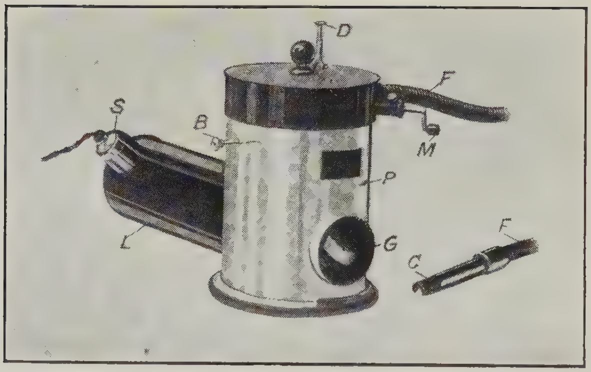

FIG. 1.

[To face page 41D.

DEMONSTRATIONS.

The following demonstrations were shown at the afternoon meeting :—

1. " A Method of Measuring X-Ray Intensity," by Major C. E. S. PHILLIPS. An apparatus employing an improved form of the Self-charging Electroscope, described in the " Proceedings " of the Physical Society, Vol. 34, Part 5, Page 213. Various types of ionisation chambers can be used, and readings can be taken by an observer at a safe distance from the apparatus.

2. " Intermittent Discharge from a Sectorless Static Machine," by E. J. EVANS, B.Sc. A static machine, although affording a constant voltage, has been found by Mr. Evans to give an intermittent discharge with both Coolidge and Geissler tubes. For a helium tube the intermittency was demonstrated by means of a rotating mirror, and it was shown that the frequency changes when the speed of the machine or the resistance in series with the tube is altered, or when the tube is shunted by a condenser.

3. "An X-Ray Balance," by L. H. CLARK, M.Sc. The radiation to be measured and that from a fixed quantity of radium are caused simultaneously to affect a double ionisation-chamber, the effects being balanced against one another so as to produce a steady deflection of a gold leaf. The method has been described in the Philosophical Magazine, Vol. 44, December, 1922.

4. "Dr. Solomon's Ionometer," by H. B. GOUGH, Sunic Research Laboratories. The principle of this apparatus is based upon the fact that when an electrified body, for example, the leaf of an electroscope, is exposed to the influence of a beam of X-rays, it loses its charge owing to the ionisation of the surrounding air.

If the ionisation current is measured by timing the rate of fall of the leaf of the electroscope, we have a measurement of the intensity of the radiation.

The value of this ionisation current is directly proportional to the amount of energy absorbed by the surrounding air. In the case of this instrument the air is contained in a small chamber, which will be described in detail later in this Paper.

Further, it has been proved experimentally that the ratio of the coefficients of absorption of air and of tissue does not vary to any great extent with the wave-length of the radiation.

It therefore follows that if the ionisation current is measured as previously described, we shall know how much radiation is being absorbed by the air of the chamber and consequently the amount being absorbed by the tissue, as these two values are directly proportional to each other.

The apparatus for this purpose here described was designed by Dr. Solomon and consists of three main parts, viz., the measuring instrument or electrometer, the conductor and the ionisation chamber.

Fig. 1 shows the apparatus with the exception of the rigid part of the connecting rod. P is the electrometer, C the ionisation chamber and FF the flexible parts of the connecting rod. An optical system L is used for projecting upon a ground-glass screen G a sharp image of the gold leaf. Engraved upon the glass is a graduated scale.

The source of light is a 25 watt gas filled lamp of special design, having a straight

filament enabling the scale to be evenly illuminated. An adjustable lamp-holder S is fitted for focusing purposes, and in front of the scale a magnifying lens is arranged to enable the operator to read the scale easily.

Fig. 2 shows the apparatus in section. The walls of the electrometer P are made of lead 4 mm. thick and serve to protect the apparatus from stray ionising radiation and stray electrostatic fields. The walls are "earthed" through the terminal T. The gold leaf L is supported upon a brass stem H which is insulated from the walls by means of ebonite and sulphur. The stem is connected to the connecting wire K by means of a small spring C. The connecting wire is carefully insulated by means of amber olives in the two flexible ends F_1 and F_2 of the rod. At the end of the rod is the ionisation chamber A. An air condenser or additional capacity is connected if desired to the leaf system by means of the small spring S. This extra capacity reduces the sensitivity of the apparatus about three and a half times, thus making measurements of long duration possible. This

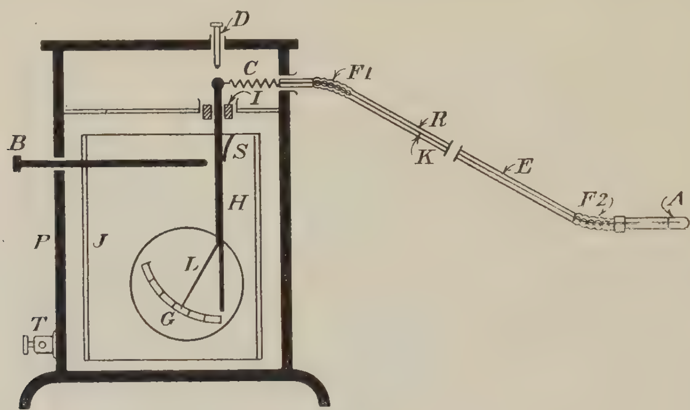

FIG. 2.

condenser consists of the walls of the chamber and a brass tube J supported by small ebonite insulating blocks. The leaf is charged by a small friction machine fitted inside the top of the electrometer (not shown in the diagram).

Doubtless many will appreciate this device after having used an ordinary electroscope charged by means of an electrified ebonite rod, with the result that at times the leaf receives too great a charge, in which case the leaf may be damaged, or, on the other hand, the leaf may not be charged sufficiently and time is thus wasted in arranging the leaf as required. With this instrument, as the small handle of the friction machine is slowly rotated so the leaf slowly rises over the scale. As the handle is released a spring carries the device away from contact with the leaf system and the apparatus is then ready for work. Should the leaf be charged to a higher point on the scale than is required, the leaf may be slowly discharged by a semi-conducting discharger D.

Fig. 3 shows the ionisation chamber in detail. The chamber itself consists of a small cylindrical tube of graphite I containing a volume of air J. In the centre of the chamber supported by an amber block G is a stem of graphite H, which is

connected by means of a wire F and a small spring D to the wire of the conducting rod. The chamber is fitted to the conducting rod by the bayonet fitting A. The dimensions of the chamber are such that it may be placed upon the skin or even introduced into the natural cavities of the body.

The apparatus is standardised with a known quantity of radium.

The ionisation produced by 1 gramme of radium element in one second placed at a distance of 20 mm. and screened by 0·5 mm. of platinum is denoted by the letter R. The ionisation produced by this gramme of radium will cause the leaf to fall through the full number of divisions of the scale, viz., 50, in a certain time, which time is a function of the capacity of the apparatus. This time expressed in seconds represents the number of R units which correspond to the total graduation of the scale and is known as the constant of the apparatus. There are two values of this constant for the apparatus, K_1 corresponding to the large capacity, that is with the additional air condenser connected to the leaf system, and K_2 corresponding to the small capacity.

Dr. Solomon, after considerable experimental work, states that $1{,}000R = 5\ H$ or tint B of the Sabouraud Noire radiometer. As the constant K_1 is roughly equivalent to 500 R, it will be seen that the full scale corresponds to approximately 2·5 H. To predetermine the time of exposure for a skin dose equal to tint B Sabouraud Noire radiometer, the ionisation chamber is placed at an equal distance from the anticathode as the skin of the patient. The X-ray plant is switched on and the

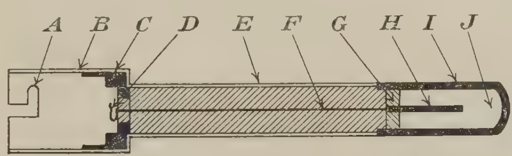

FIG. 3.

leaf previously charged is timed by means of a stop watch over 50 small divisions of the scale. It is necessary for the purposes of this calculation to assume that the electrical conditions of the generating plant and the consequent tube emission are constant. Reference must now be made to the constant K_2 of the instrument. In the case of the instrument shown here this value is 130 R. If this value is divided by the time of fall in seconds, the value of the incident radiation is known in terms of R per second. Suppose the time of fall was found to be 90 seconds, then the intensity of radiation or the value of the incident dose equals $\frac{130}{90} = 1{\cdot}44\ R$ per second. As $1{,}000\ R = 5H$, or tint B Sabouraud Noire radiometer, the total time for the exposure will be $\frac{1{,}000}{1{\cdot}44} = 694$ seconds. Should electrical conditions be unstable the *total* X-ray dose may be measured by means of the ionometer. The ionisation chamber is placed upon the skin of the patient and the leaf connected up to the large capacity. The number of divisions through which the leaf falls is carefully noted at the end of the treatment. Reference to constant K_1 will show that each small division of the scale in the case of the instrument shown here equals 10 R. Suppose the number of small divisions through which the leaf has fallen is 40, the total dose applied will equal $10 \times 40 = 400\ R$, or 2 H.

For deep therapy measurements, if the ionisation chamber is not introduced into the natural cavities of the body, it is necessary to discover the ratio of the depth dose to the incident dose. For this purpose the " Ionometric Standardiser " (Fig. 4) is used, which consists of a vessel containing water into which the ionisation

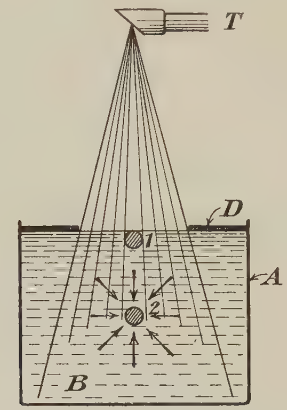

FIG. 4.

chamber may be introduced at a depth of 10 cm.; the dimensions of the beam, the height of the tube and the conditions of filtration being predetermined.

The coefficient of absorption of water being very nearly equal to that of the tissues, an effective value of the radiation is thus obtained, having taken into account all diffused secondary radiation.

To discover the ratio of the depth dose to the incident dose is a simple matter. The leaf is charged and its fall timed over the full scale with the ionisation chamber placed at 10 cm. depth in the water, this time being represented by T_1. The experiment is repeated, except that the ionisation chamber is this time placed at the surface of the water. The time of fall is noted and represented by T_2. Then T_2/T_1 is the value required. Any measurements taken at skin distance may be converted into depth measurements by multiplying by T_2/T_1.

Another use to which the instrument may be put is to measure the coefficient of transmission of a filter. By two successive measurements with the same electrical conditions the intensity after filtration I_1 and the intensity before filtration I_2 are found. Then the ratio $\frac{I_1}{I_2}$ gives the coefficient of transmission of the filter.

The instrument is simple to operate and measurements made with it are reliable.

5. " A Spectrometer for Measuring End Radiation," by W. E. SCHALL, B.Sc. This instrument, due to Drs. Staunig, March and Fritz, of Innsbruck, is an X-Ray spectrometer which combines the methods of Laue and the Braggs. The beam of X-rays is passed through a crytsal, and after reflection has taken place at the internal atomic planes of the crystal the reflected beam falls on a fluorescent screen.

Fig. 1 is a diagram of the instrument. D_1 and D_2 are two slits in thick lead plates, which serve to cut down the incident beam to a narrow pencil. C is the

crystal, which can be rotated. S is the fluorescent screen. As the crystal is rotated a point is reached when the reflected beam flashes up suddenly on the screen. A similar point may, by rotating the crystal, be found on the other side of the central undeflected ray. These points, represented in the figure by λ_0 and λ'_0, are quite sharply defined. A scale is provided whereby the wave-length of the radiation can be read off directly in Ångstrom units, with an error not exceeding 0·005Å.

The instrument may be applied to the calibration of X-ray tubes for purposes

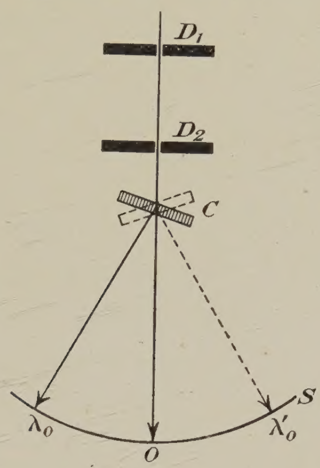

FIG. 1.

of radiography and radiotherapy. (For further description, *see* Jour. Rönt. Soc., April, 1923.)

6. "The Ondoscope," by F. L. HOPWOOD, D.Sc. Designed for exhibiting the wave form of generators used with X-ray tubes. A vertical neon or air tube is rotated about a parallel axis while connected in series with the machine to be tested. As the length of the glow is proportional to the current passing, a luminous graph of the wave form is thus obtained. The device is described in the Journal of the Röntgen Society, Vol. 19, January, 1923.

DISCUSSION ON THE DEMONSTRATIONS.

Mr. M. A. CODD : With regard to Mr. Evans's demonstration, he suggested that the current from a Wimshurst machine is itself intermittent. There can be no doubt that the current in an X-ray tube is so.

Dr. D. OWEN : If, as appears to be the case, the X-rays come off in intermittent spurts, it seems possible that there is an optimum group frequency. As this frequency can be controlled by varying the capacity shunted across the tube or otherwise, the matter may repay the attention of X-ray workers.

Mr. EVANS (in reply) said that work on the characteristics of the static machine, on which he was at the present time engaged, favoured the view that the cause of the intermittency lay in the X-ray tube, and not in the static machine. It had been observed by Dauvillier that a gas bulb gave an intermittent discharge even when supplied by a secondary battery. He (the speaker) was not aware that the like effect had been observed in the case of the Coolidge tube prior to the work by Mr. Harlow and himself as recorded in their Paper contributed to the present discussion.

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